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A METHODOLOGY FOR ASSESSING ALTERNATIVES TO REDUCE SHIP COLLISIONS

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DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

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16. Abstract

This reserach analyzes the ship collision problem in and around United States ports and develops a methocology to allow cost effective assessment of alternatives to reduce ship collisions. By analytical and statistical means, a mathematical model is developed to predict ship collisions in ports and to evaluate the parameters for Pacific Coast ports. The Collision Prediction Model is based on ship factors, port factors and exposure criteria. The model provides for including the effectiveness of various collision reduction methods through the use of multiplicative factors.

Examples of benefit cost analyses are presented based on Net Present Value, forecasts of the Collision Prediction Model and the effectiveness of various collision reduction methods. Sensitivity analyses are conducted to demonstrate the ability of the proposed methods to identify critical ranges for important parameters.

The methods described provide decision makers with an analytical aid for making decisions. Collision trends and priorities for alleviating the ship collision problem can be established and resources allocated appropriately.

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PREFACE

This work was performed by Ronald Rhys Morgan in partial satisfaction of the requirements for the degree of Doctor of Philosophy in Engineering under the close supervision of Doctor Russell R. O'Neill, Dean, School of Engineering and Applied Science, University of California, Los Angeles. The following personnel also contributed significantly to the effort: Doctor Shahen A. Hovanessian and Mr. Chung L. Wong of Hughes Aircraft Company and Doctor Robert S. Elliott of University of California, Los Angeles.

During this research, significant contributions and support were provided by United States Coast Guard personnel. The following personnel contributed significantly in the form of providing data, references, technical expertise and review of draft material. Without their assistance, this work would not have been accomplished. My appreciation is extended to Commanders Warren Snider, James Card and William Ecker; Lieutenant Commanders Lawrence Olson and Karl Johnson and Lieutenants James Cumerford and Derek Capizzi. In addition, Dr. John Gardenier provided substantial support and assistance.

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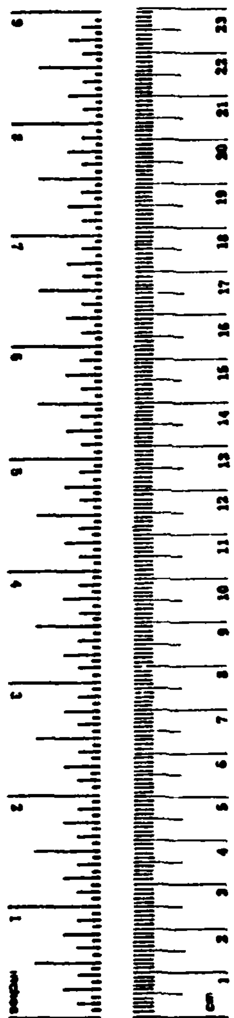
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

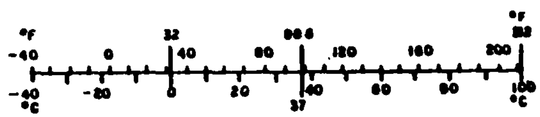
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. SUMMARY

Ship collisions represent a significant problem for the United States. Statistics show that the problem of ship collisions is longstanding, with a trend of increasing collisions and property damage. For the 11-year period from 1966 through 1976, 16,559 collisions involving 32,433 commercial vessels were reported to the Coast Guard. These collisions resulted in $710 million in property damage, 1,307 vessels lost, 619 deaths and 509 serious injuries. Adjusted to 1977 dollars, damages for this 11-year period are approximately one billion dollars. In addition to the available statistical data are the unknown ecological impacts. There is also the ever present potential for major marine catastrophes. This research analyzes ship collisions in and around United States Pacific Coast ports and develops a methodology to allow cost effective assessment of alternatives available to reduce ship collisions.

Through analytical and statistical means, this paper presents a mathematical model to predict ship collisions in ports and to evaluate the parameters for Pacific Coast ports. This Collision Prediction Model (CPM) is based on ship factors, port factors and exposure criteria. Using the variables which the historical data show to be highly significant, the Collision Prediction Model is derived to be:

$$\text{Number of collisions} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{p=1}^{q} Y_{SF}\, Y_{PF}\, T$$

$$= \sum_{i=1}^{5} \sum_{j=1}^{3} \sum_{p=1}^{21} \underbrace{(0.000082)(1.0058)^{x}(\pi_{ij})}_{\text{ship factors}} \underbrace{(\pi_{p})}_{\substack{\text{port}\\ \text{factors}}} \underbrace{(T_{ijp})}_{\substack{\text{exposure}\\ \text{criteria}}}$$

The model incorporates the effectiveness of various collision reduction methods through the use of multiplicative factors.

The methodology used to derive the Collision Prediction Model is evaluated by applying the methodology to additional data bases. The model's ability to predict collisions is tested by forecasting collisions for 1977 without a priori knowledge of 1977 collision statistics. Absolute value and relative ranking comparisons are conducted to validate both the methodology used to derive the *Collision Prediction Model* and the model's ability to forecast collisions. Sensitivity analyses are conducted to evaluate the impact of Collision Prediction Model forecasting errors. Provisions for dynamic updating of the model are defined in order to improve the model's ability to predict collisions for a wide range of ports over extended periods of time. The methods chosen to allow dynamic updating of the Collision Prediction Model include use of a recursive weighted least squares solution, exponential curve fitting and a statistical test.

A methodology that examines the effects of alternatives to reduce collisions is described. The methodology develops a set of criteria, called a Casualty Analysis Gauge, to determine which collisions in a population are preventable by a particular collision reduction method. This method, previously derived by W. A. Dunn, J. S. Gardenier and others in <u>Spill Risk Analysis Program</u>

(References 1 and 2), determines the multiplicative factors for use with the Collision Prediction Model.

Computer programs are used extensively in this study to sort the massive amount of data and determine key values by statistical means, such as the cost of collisions for various sizes and types of vessels. Examples of benefit-cost analyses are presented based on Net Present Value, forecasts of the Collision Prediction Model, and the effectiveness of various collision reduction methods. Sensitivity analyses are conducted to demonstrate the ability of the proposed methods to identify critical ranges for important parameters.

The methods described provide decision makers with an analytical aid for making decisions. Those who could benefit from the proposed analytical approach include federal agencies such as the United States Coast Guard and Army Corps of Engineers, local agencies such as port harbormasters and pilot associations, shipping and shipbuilding companies and insurance companies covering ships and ports. Collision trends and priorities for alleviating the ship collision problem can be established and resources allocated appropriately.

II. COLLISION PREDICTION MODEL FORMULATION

Definition of Collision

The term collision must be defined to provide the framework to generate the Collision Prediction Model. Generally, this paper defines collision as the act of a vessel colliding with another object. Specifically, it incorporates in the definition the 12 categories of collisions used by the United States Coast Guard in recording casualty information (Reference 3). These categories are:

1. Collision with one or more vessels - meeting situation.
2. Collision with one or more vessels - crossing situation.
3. Collision with one or more vessels - overtaking situation.
4. Collision with vessel anchored or moored (not while docking or undocking). This is often referred to as ramming.
5. Collision with vessel while docking or undocking.
6. Collision with vessel in fog. This category takes precedence over categories 1, 2, and 3.
7. Collision with vessel that is not otherwise classified (NOC). This includes minor bumps between tugs and vessel.
8. Collision with floating or submerged objects (other than ground).
9. Collision with fixed objects such as piers and bridges.
10. Collision with ice or ice fields.
11. Collision with aids to navigation, fixed or floating.
12. Collision with object other than vessel not otherwise classified, such as offshore rigs and seaplanes. (This category is generally referred to as miscellaneous.)

In addition, groundings (collisions with the ground) in and around ports are a major source of damages and injuries. This type of collision can be evaluated by using the same techniques used for other types of collisions. In this paper, the term collision includes all of the 12 collision and ramming categories listed above, plus groundings that result in vessel damage.

Collision Statistics

In fiscal year 1976*, 2,023 collisions, most of them in or near harbors, were reported to the Coast Guard. The collisions involved 4,261 commercial vessels and resulted in 76 vessels lost, 36 deaths, and 50 serious injuries. A conservative estimate of the property damage caused by the collisions is over $127 million. Figures for the past 11 years (1966-1976) total 32,433 commercial vessels lost, 619 deaths, and 509 serious injuries. Adjusted to 1977 dollars, damages for this period are approximately 1 billion dollars (Table I).

Collision Prediction Model Concept

In order to provide a foundation for predicting collisions, the number of collisions for a particular time period for any port can be represented as a function of ship factors, port factors, and the degree of exposure to collision situations. The mathematical model is formulated by identifying quantitatively ship and port characteristics and exposure criteria.

*During 1976, the start of the fiscal year was moved from 1 July to 1 October. Therefore, FY'76 covered a 15-month period.

TABLE I. COLLISION SUMMARY (1966 - 1976)

(Sources: U. S. Coast Guard Vessel Casualty Records as published annually in the Proceedings of the U. S. Marine Safety Council and U. S. Bureau of Labor Statistics as published in the Statistical Abstract of the United States, 1977 (98th edition), Washington, D.C., 1977, p 470.

FISCAL YEAR	NUMBER OF COLLISIONS	SHIPS INVOLVED	SHIPS LOST	DEATHS	SERIOUS+ INJURIES	$M DAMAGES	CONSUMER* PRICE INDEX	$M DAMAGES (1977)
1966	1,224	2,035	133	102	57	43	1.857	80
1967	1,301	2,229	124	49	50	43	1.805	78
1968	1,347	2,611	98	33	32	42	1.733	73
1969	1,461	2,790	143	98	87	38	1.644	62
1970	1,410	2,701	124	24	26	41	1.552	64
1971	1,491	2,837	164	75	52	42	1.487	62
1972	1,389	2,869	141	43	31	56	1.440	81
1973	1,576	3,149	106	45	30	82	1.357	111
1974	1,606	3,288	110	40	55	80	1.224	98
1975	1,731	3,663	88	74	39	123	1.121	138
1976	2,023	4,261	76	36	50	120	1.060	127
TOTAL	16,559	32,433	1307	619	509	710	Not applicable	974

+ Injuries incapacitating a person in excess of 72 hours.
* Adjusted to 1977 dollars.

Ship factors include such parameters as size, type, age, equipment, training and personnel qualification and speed. This list is not inclusive but rather indicates the kinds of parameters that can be associated with a ship and which may contribute to collisions. The ship factor portion of the mathematical model assigns values to specific or grouped parameters based on empirical data and statistical analysis defining their contribution to collisions. The mathematical model is formulated in such a way that the ship factor equations can be modified to provide increased accuracy in predicting collisions, based on latest available data.

Port factors include such parameters as the amount of traffic, port physical characteristics, weather conditions, visibility, navigational aids, tides and currents, depth of water, and port equipment. Again, the list is not inclusive, but serves to identify certain parameters that may contribute to collisions. The port factor contribution to the mathematical model is based upon statistical evaluation of empirical data to determine mathematical relationships for individual or grouped parameters. Similar to the portion of the model for ship factors, the port factor portion is flexible in that it can be modified to provide increased accuracy, based on latest available data.

The degree to which parameters can be identified and numerical values assigned is heavily dependent upon the available empirical data. As will be shown, it is necessary to aggregate most parameters in developing the mathematical model.

After ship and port factor contributions to collisions are

identified, they must be applied to quantitative measures of exposure to collision situations to predict the number of collisions. The quantitative measures of exposure can be thought of as "exposure criteria." Since a ship is exposed to a potential collision whenever it gets under way from or enters a port, the inbound and outbound transits are defined as the "exposure criteria." Thus, the number of ship transits is used to determine quantitatively the measure of exposure to collision situations.

The first step in generating the mathematical model is formulated as follows:

$$\text{Number of collisions} = Y_{SF}\, Y_{PF}\, T \qquad (1)$$

where

Y_{SF} = ship factor contribution.

Y_{PF} = port factor contribution.

T = exposure criteria (number of transits).

The number of collisions divided by the number of exposures to collision circumstances, T, will result in a collision rate.

$$\frac{\text{Number of collisions}}{T} = Y_{SF}\, Y_{PF} = \underbrace{\lambda}_{\text{Collision rate}} \qquad (2)$$

Since there are many parameters associated with ship and port factors, the ship and port factor functions (Y_{SF}, Y_{PF}) can be expressed mathematically as a family of equations or as a family of coefficients. The approach selected was to define the ship and port factors as coefficients. This approach was chosen because of the capability to incorporate new coefficients or modify existing coefficients as necessary to reflect changing conditions or additional

data. Sufficient coefficients are assigned to model adequately a wide range of collisions. For example, ship factors could change as a function of ship size, and therefore several ship factor coefficients would be required. Similarly, ship factor coefficients may change as function of ship size and type of ship, and therefore additional coefficients or multiplicative factors would be required to emulate the effect of several parameters. Similar identification and numerical assignment of coefficients are conducted until an accurate model for predicting collisions is generated. The use of coefficients in conjunction with the quantitative measure of exposure to collision situations can be expressed as follows:

$$\text{Number of collisions} = \sum_{i=1}^{m} \sum_{j=1}^{n} \cdots \sum_{z=1}^{q} Y_{SF_{ij\cdots z}} Y_{PF_{ij\cdots z}} T_{ij\cdots z}$$

$$= \sum_{i=1}^{m} \sum_{j=1}^{n} \cdots \sum_{z=1}^{q} \lambda_{ij\cdots z} T_{ij\cdots z} \qquad (3)$$

where

$Y_{SF_{ij\cdots z}}$ = Ship factor coefficients for $i\ j\cdots z$ subcategory.

$Y_{PF_{ij\cdots z}}$ = Port factor coefficients for $i\ j\cdots z$ subcategory.

$T_{ij\cdots z}$ = Transits for $i\ j\cdots z$ subcategory.

The i^{th} category allows ship and port factor coefficients to be assigned mathematically for a particular parameter or attribute (e.g., ship size). Additional coefficients are assigned as necessary and are represented by additional subscripts (e.g., j, k$\cdots$z).

As the additional contributions to collisions of specific parameters are identified, their effects are included in the model by the addition of multiplicative factors. The multiplicative factors (π) adjust the model predictions by accounting for the contribution of a specific parameter. For example, the model might predict the number of collisions for ships as a function of ship length. If, based upon statistical analysis, a contribution as to ship-type for ships of these lengths can be identified and quantified, a multiplicative factor would be included for the type of ship (e.g., tanker, passenger, etc.). For this example, the contributions of ship length and type have been used to define the collision rate λ. This would be represented as:

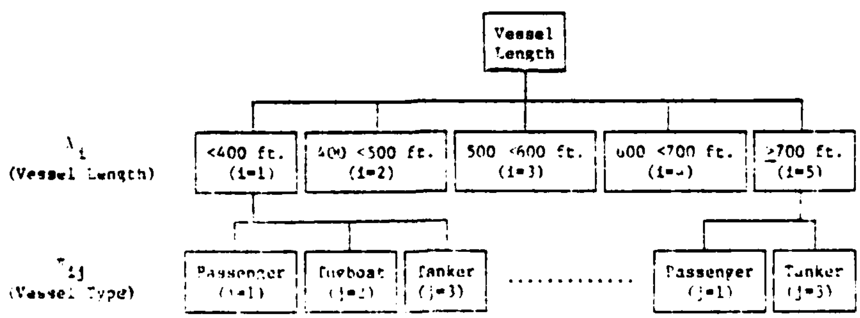
$$\lambda_{ij} = \lambda_i \pi_{ij}$$

where λ_{ij} = collision rate for length category i and ship-type j.

λ_i = collision rate for length category i.

π_{ij} = multiplicative factor to account for the contribution of ship-type j in relation to ship length category i.

Figure 1 shows this technique used in developing the model.



NOTE: The tugboat category is not shown under the larger ship length categories since tugboats do not exceed 400 feet in length.

Figure 1. Model Development for Ship Related Parameters

Similarly, incorporation of other parameters would be expressed as:

$$\lambda_{ij \cdots \ell} = \lambda_i \pi_{ij \cdots \ell}$$

where

$\lambda_{ij \cdots \ell}$ = collision rate for i, j, $\cdots$ ℓ subcategory.

λ_i = collision rate for i^{th} category.

$\pi_{ij \cdots \ell}$ = multiplicative factor to account for the contribution of j, k $\cdots$ ℓ subcategory to λ_i.

Other parameters, such as port factors, are added to the model as additional multiplicative factors. Since it is assumed that a port factor can be expressed independently of ship factors, the port factor contribution is included separately as π_p. This is seen as:

$$\lambda_{ij \ldots \ell p} = \lambda_i \pi_{ij \ldots \ell} \pi_p$$

where

$\lambda_{ij \ldots \ell p}$ = collision rate for i, j $\cdots$ ℓ, p subcategory.

λ_i = collision rate for length category i.

$\pi_{ij \ldots \ell}$ = multiplicative factor to account for the contribution of j $\cdots$ ℓ subcategory to λ_i.

π_p = port factor contribution (e.g. p=1 is Long Beach, p=2 is San Francisco, etc.).

The degree of identification of coefficients for individual or grouped parameters is determined by the available data. Because of shortcomings in recorded collision and transit data, it is anticipated that few individual parameters can be isolated and identified with

regard to their specific contribution to causing collisions. Rather, it is expected that parameters will have to be grouped together. For a single parameter (e.g., ship length), the generalized mathematical model is proposed as follows:

$$\text{Number of collisions} = \sum_{i=1}^{m} \underbrace{\lambda_i}_{\substack{\text{ship factors,} \\ \text{port factors}}} \underbrace{T_i}_{\substack{\text{exposure} \\ \text{criteria}}} \tag{4}$$

If two levels of ship coefficients and a single level of port coefficients can be established, the generalized mathematical model becomes:

$$\text{Number of collisions} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{p=1}^{r} \lambda_{ijp} T_{ijp} = \lambda_i \pi_{ij} \pi_p T_{ijp} \tag{5}$$

Further identification would continue until sufficient coefficients are determined to model adequately a wide range of collisions. The development of the equations for ship factors, port factors and exposure criteria and the validation of the model are described in Sections VII and VIII.

III. PREVIOUS RESEARCH

Maritime related journals, technical reports and articles were reviewed to support the research documented in this paper. Maritime safety is a markedly international field and therefore many of the articles were written by Japanese, European and United States researchers. Although there are many distinguished contributions to the field of maritime safety, only those most directly relied upon in the preparation of this research are cited explicitly. This subsection describes several of the works most relevant to collision prediction and assessment of the effectiveness of collision reduction methods.

Spill Risk Analysis Program - Phase II Methodology Development and Demonstration (AD-785 026), July 1974.

This work develops and demonstrates systematic methods of assessing the effectiveness of Merchant Marine safety regulations. The methods were designed primarily to assist Coast Guard regulatory decision makers in their selection of alternative means of reducing marine transportation casualties and spills of hazardous or polluting materials. The methods developed include both analytical and logical modeling of merchant marine operations and the casualty process. The analytical model is developed to emulate the physical parameters involved in oil spills, such as vessel speeds and rupture resistance. The analytical model provides for estimating the number of oil spills and the impact of varying parameters involved in the oil spill process.

There are significant differences in the approach used to model collisions in the Spill Risk Analysis and that used in this paper.

The two models differ in the definition of exposure criteria and in the definition of an error or collision rate that is used in conjunction with exposure criteria to determine collision situations. In the spill risk analytical model, the probability of a collision is determined by the time spent within a collision region, T_{CR}, and by errors which cause ships to end up on a collision course. If we denote the probability of such errors per unit time as λ and the time spent within the collision region as T_{CR}, then we may represent the probability of a collision given an exposure as:

$$P(C|E) = \lambda\, T_{CR}.$$

The report states, "At the present stage of development the spill-risk model treats λ as an input parameter which can be altered in the conduct of sensitivity analysis, but no explicit models of λ or its components have been developed in this phase of the research. This parameter is a measure of the error rate of both mechanical and human errors and could be further modeled if actions were envisioned which would change it."

In order to estimate the number of collisions for a waterway, λ would have to be determined, the waterway would have to be defined in a series of channel segments, and scenario submodels (which relate vessel characteristics and operations) would have to be developed to determine the conditions under which a vessel is exposed to all types of collision situations. A different approach is used in this later research, wherein exposure criteria are defined as transits entering and leaving ports, and a collision rate is defined quantitatively based on ship and port characteristics using

statistical and numerical analysis of historical collision data. No additional modeling of error rates, waterways or collision scenarios is required to predict the number of collisions for the Pacific Coast ports analyzed.

Of the methods described in the Spill Risk Analysis study, one that is of particular interest to this dissertation examines the probable effects of regulatory and enforcement actions. This methodology is used in the present research in conjunction with the Collision Prediction Model to define the effectiveness of alternatives for reducing collisions. Based on the results obtained, benefit-cost analyses can be accomplished. The methodology for examining the probable effects of regulatory and enforcement actions and its use in this research are described in Section IX of this paper.

Spill Risk Analysis Program: Methodology Development and Demonstration Final Report (ADA-043 054), April 1977.

The first work cited was most helpful to this researcher particularly in the area of identifying a methodology for assessing the effectiveness of alternatives for reducing collisions. Further development and application of the concepts documented in the earlier work (July 1974) are available in this referenced subsequent Final Report. The Final Report supplements but does not replace information contained in the July 1974 publication and therefore both reports are valuable references for researchers in the field of maritime safety.

Vessel Traffic Systems Issue Study (Volumes I through IV), AD-770 711, AD-770 712, AD-771 982, AD-774 983, March 1973.

An extensive study on Vessel Traffic Systems is documented in

these four volumes. Volume I is an executive summary that includes the major conclusions and recommendations. Volume II presents the findings of the study and includes a synopsis of a Computer Sciences Corporation study. Volume III details relevant portions of the Computer Sciences Corporation study. Volume IV describes a complete management plan for the Vessel Traffic System program.

Of the four volumes, Volume III is the most relevant to this research. It documents Computer Sciences Corporation's efforts to assist the U.S. Coast Guard in planning Vessel Traffic Systems. The study deals with three specific tasks:

1. Development of a conceptual framework for vessel traffic systems.
2. Identification of participants' roles in the system.
3. Development of an algorithm to determine the needs for various levels of Vessel Traffic Systems (traffic separation scheme, vessel movement reporting system, basic surveillance, advanced surveillance and automated advanced surveillance).

The third task relates to the research conducted in this paper insofar as it generates a basis for predicting collisions and makes estimates as to the percent reduction in collisions and groundings for various levels of vessel traffic management. However, the algorithm developed in the Vessel Traffic Systems study differs from the Collision Prediction Model proposed in this paper in determining the collision rate to be used. The Vessel Traffic Systems study bases its approach solely on historical data to obtain collision rates as a function of ship-type. It does not attempt to identify specific

ship and port factors based on statistical and numerical analysis for use in predicting collisions.

The Vessel Traffic Systems study also differs from this report in that it does not use ship size as a key ship characteristic. The report states that "it was decided to eliminate separate calculations for loss hazard on the basis of ship size." However, the report recognizes the potential importance of ship size when it notes that "...for future application, ship size may be considered as a subset of the ship type."

Operational Research and Cost Benefit Analysis on Navigation with Particular Reference to Marine Accidents; Stratton, A. and Silver, W. E., Journal of Navigation, Volume 23, No. 3, July 1970, pp 325-340.

The authors point out the need for a systematic operations research approach to analyze marine accidents and cost-benefit analysis to quantify potential gains of developments in navigation. They discuss that the objective of navigation is not only to ensure safe operation but also to result in economical operation of a vessel. The cost of accidents is spread among the operators, through loss of revenue and increase in insurance rates, and on society through loss of life, damage to property, loss of earnings and ecological damage. The case of the tanker Torrey Canyon which grounded off the English coast and produced massive oil spills is used as an example of social costs resulting from major pollution. (The Torrey Canyon settlement in 1970 of over eight million dollars is reportedly less than the total expenses involved.)

Since the relationship between advances in navigation and cost-

benefit analysis are complex, unless the nature of their interactions can be quantified, a very high degree of subjective judgment will be used in regard to decisions on navigational equipment. The article states "To the best knowledge of the authors no overall operational or systems analysis of this type has been done in either the marine or aeronautical field..." The article further states "...little attention has been given to cost-benefit analysis on marine accidents. A major problem exists in obtaining the necessary data on cost of ship damage and on relating cost benefits to navigational effectiveness." The research developed and documented in this dissertation defines an overall systematic approach for accomplishing exactly the type benefit-cost analysis for marine collisions that A. Stratton and W. E. Silver identify as needed.

The authors describe how statistical analysis can be used in conjunction with benefit-cost analysis. One of the techniques they use is to test a null hypothesis (i.e., there is no real significant difference between samples of the population). This same statistical technique is used in this work to show a significant difference between tankers and passenger/cargo vessel collision statistics for very large ships (Sections VI and VII).

<u>Estimating the Dangers Presented to Ports and Waterways from the Marine Transportation of Hazardous Cargoes: An Analytical Model</u>; Wells, R. R., Blecker, H. G., and McDonald, B. L., unpublished paper.

This unpublished paper by Coast Guard personnel defines an approach for model formulation for comparing anticipated benefits of programs aimed at marine hazard reduction with the cost of

accomplishing such reductions. The concepts and formulations presented in the paper are regarded by the authors as preliminary steps toward understanding the mechanisms and risk levels associated with the marine transport of hazardous materials in port areas. Although the model is markedly different than the Collision Prediction Model, some of the insights used in developing their model are related to those independently arrived at in this research. The major difference between the referenced model and the Collision Prediction Model is that the referenced model output is the "Total expected loss for a single specific incident" whereas the CPM output is "Number of collisions." The similar concepts used in developing the two models include identifying major factors that can be mathematically combined to produce the desired result, the identification of sub-factors for quantification of parameters, and data sources that could provide a basis for quantifying sub-factors and major factors. One of the major factors identified in the referenced model is $P_{jk\ell}$. (The probability of an accident "j" occurring with commodity group "k," in location "ℓ"). This term is somewhat analagous to the combined ship factor and port factor components of the Collision Prediction Model. The $P_{jk\ell}$ factor is postulated further as probably containing sub-factors that combine in a complex multiplicative manner. No attempt is made in the referenced work to quantify the model factors or postulated sub-factors. It is interesting that two of the sub-factors postulated for $P_{jk\ell}$ are traffic density and size of vessel, both of which have been identified and quantified in the Collision Prediction Model.

This author recently received this unpublished internal Coast Guard paper from a reviewer of this thesis and wishes to give the referenced paper's authors credit for employing some similar concepts in developing their model.

Summary of Background Research Investigation

The application of engineering techniques to maritime research to predict collisions and assess alternatives is relatively new. Several research projects undertaken in the United States and elsewhere deal with predicting collisions. However, none of these develops a Collision Prediction Model based on ship factors, port factors and exposure criteria. Historically, collision predictions or oil spillage estimates are based on empirical data and extrapolations to new situations. The models generally are not designed to incorporate new parameters or to allow for incorporation of latest available data for dynamic updating of the model. None of the models was generated from one set of data and validated by means of another set of data. Agencies sponsoring research in this area appear to be concerned with the investigation and evaluation of specific concerns or projects (e.g., Vessel Traffic Systems).

IV. SOURCES OF DATA

Several sources of data can be used for collision analysis. The most valuable of these are the Coast Guard's Vessel Casualty Records, the U. S. Army's annual publication Waterborne Commerce of the United States and the U. S. Army's Port Series reports.

Vessel Casualty Records

United States law requires that the master of a commercial vessel report a marine casualty as soon as possible to the Officer-In-Charge, Marine Inspection, U. S. Coast Guard, whenever a casualty results in any of the following:

1. Damage to property in excess of $1500.
2. Material damage affecting the seaworthiness and efficiency of a vessel.
3. Stranding or grounding.
4. Loss of life.
5. Injury causing any person(s) to remain incapacitated for a period in excess of 72 hours.

Information concerning a casualty is submitted by the vessels' operators to the Coast Guard utilizing Department of Transportation U. S. Coast Guard Form CG-2692. Coast Guard personnel record the data on microfilm and also code and store the data on computer tapes. The accuracy of the data transfer is highly dependent on the individual doing the computer coding. As discussed later in this section, transcription errors do exist.

Table II is an example of the extensive collision information

TABLE II. MARINE COLLISION INFORMATION REQUIRED BY THE COAST GUARD (FORM CG-2692)

	Coast Guard inspected
*	Type of vessel
	Propulsion type
	Person in charge of vessel maneuvers
	Date
*	Special indicator (e.g., pollution)
	Time of day
	Vessel involvement (primary, secondary, etc.)
*	Gross tonnage
*	Length
	Hull materials
	Age of vessel
*	Location
	Nature of casualty
*	Primary cause
*	Area of causal connection
*	Additional contributory factors
	Weather
*	Visibility
	Wind
	Sea conditions
	Personnel killed or injured
	Estimated vessel, cargo and property losses
	Vessel lost
	Vessel nationality
	Narrative description of casualty

*Discussed on the following pages

required to be reported to the Coast Guard. Copies of computer tapes containing all casualty information since Fiscal Year 1963 were provided by the Coast Guard for use in this research. Following are brief descriptions of some of the more relevant information that has been extracted from the computerized data.

Type of Vessel

Vessels are grouped into the twenty-nine major categories listed in Table III. A more detailed breakdown is available for most of these major categories. An example is provided in Table IV, which illustrates the breakouts available for tank barges (Categories 18 and 29 of Table III).

Special Indicator

Starting in Fiscal Year 1969, a special indicator category was incorporated to include additional information such as the extent of oil pollution, if any. Table V lists the additional information that became available with the inclusion of the special indicator category.

Gross Tonnage

Table VI shows the categories for gross tonnage. As Table VI shows, the largest grouping recorded on the computer tapes is 15,000 or more gross tons. A review of the Coast Guard's microfilm records in Washington, D.C., provided the exact gross tonnage for vessels greater than 15,000 tons involved in Pacific Coast collisions. The mean value of the twenty vessels involved in collisions was 22,604 gross tons. The range of tonnage was from 15,257 to 48,500 gross tons. This research assumes a nominal value of 22,500 gross tons for ships coded in the Coast Guard's Vessel Casualty Records as "over 15,000."

TABLE III. TYPE OF VESSEL

CODE	DESCRIPTION
01	Artificial Island or fixed structure, including mobile drill rigs
02	Cargo vessel (freight) (inspected U. S. vessels only)
03	Cargo barges (freight)
04	Commercial vessels that carry freight and off-shore supply vessels
05	Construction and wrecking vessels, including vessels such as drill tenders, pile drivers, derrick barges, drill ships, and barges
06	Dredges, self-propelled
07	Dredges, non self-propelled
08	Fishing vessels (excluding sport fishing, charter fishing vessels)
09	Tugs and towboats - also unmanned bow thruster unit
10	Passenger vessels, other than ferries, over 65 feet and 100 or more gross tons
11	Passenger vessels, other than ferries, over 65 feet and less than 100 gross tons
12	Passenger vessels, other than ferries, not more than 65 feet
13	Ferries over 65 feet and 100 or more gross tons, carrying passengers, or passengers and vehicles
14	Ferries over 65 feet and less than 100 gross tons, carrying passengers, or passengers and vehicles
15	Ferries no more than 65 feet, carrying passengers, or passengers and vehicles
16	Passenger barges (including ferry barges)
17	Tankships
18	Tank barges (inflammable and combustible cargoes)
19	Public vessels (passenger)
20	Public vessels (cargo), excluding GAA vessels
21	Public vessels (tanker), including USNS tankers
22	Public vessels (other)

Continued

TABLE III. TYPE OF VESSEL (Continued)

CODE	DESCRIPTION
23	All other U. S. vessels and crafts such as pleasure, research, cable-ships, seismographic, or those not otherwise classified above
24	Foreign flag vessels (passenger)
25	Foreign flag vessels (freight)
26	Foreign flag vessels (tanker)
27	Foreign flag vessels (other)
28	Cargo barges (dangerous and hazardous cargoes)
29	Tank barges (dangerous and hazardous cargoes)

TABLE IV. FURTHER CLASSIFICATION FOR TANK BARGES (Used in Conjuction with Categories 18 and 29 of Table III)

CODE	DESCRIPTION
35	Liquid cargo barge, unspecified
36	Single skinned liquid barge
37	Double skinned liquid barge, including clean petro-chemicals, e.g., aromatics, trichloride
38	Cylinder tank open hopper and void
39	Cylinder tank decked over
40	Other liquid barge, e.g., brine, drilling mud
41	LPG/LIG (butane, open hopper/propylene)
42	Chlorine
43	Sulfur, liquid
44	Ammonia, pressure tank
45	Ammonia, low temperature
46	Low temperature, etc.
47	Acid, sulfuric
48	Acid, etc.
49	Caustic, unspecified
50	Caustic soda, liquid
51	Caustic soda, high temperature
52	High temperature, etc.
69	Styrene, adiponitrile, acrylonitrile, paraxylene, vinyl acetate, ethyl benzene, alkyl benzene
71	"A" ethyl ether
99	Ammonia sulfate liquid (self unloaded), fertilizer, etc.

TABLE V. SPECIAL INDICATOR

CODE	DESCRIPTION
0	No significant data
1	Light oil pollution
2	Moderate oil pollution
3	Heavy oil pollution
4	Uninspected mobile oil drill
5	Gas chemist or gas free certificate
6	Photographs taken
7	Radiotelephone mentioned
8	Bridges involved
9	Locks or dam involved
-	Hurricane
*	Seaplane

TABLE VI. GROSS TONNAGE

CODE	DESCRIPTION
1	Not over 15
2	Over 15 to 100
3	Over 100 to 300
4	Over 300 to 500
5	Over 500 to 1000
6	Over 1000 to 5000
7	Over 5000 to 10,000
8	Over 10,000 to 15,000
9	Over 15,000
(-)	Unknown

Because ship size is shown to be a significant parameter (Section VI) and since ships are now being built that are several times larger than 15,000 gross tons, additional categorization by the Coast Guard for larger ships would be desirable for future analysis. There is no impact on this research from not having the additional categorization since the average gross tons was calculated from the microfilm records.

<u>Length</u>

A very good cataloguing by vessel length is available on the Coast Guard's computer tapes. Table VII lists the categories. Length can be correlated with size and draft for various type ships. This correlation makes it possible to relate the waterborne traffic data recorded by the U. S. Army Corps of Engineers with vessel casualties as a function of ship size.

<u>Location</u>

Location is of primary importance in this research since the mathematical model developed can be applied to specific locations. Two entries are made into the computer tapes in regard to location. The first records the general area where the casualty occurred (e.g., Atlantic Ocean, Pacific Ocean, Inland Gulf). The second lists a more specific location. Until Fiscal Year 1976, casualties occurring in United States coastal waters were recorded using the first three digits of the five digit index number given in Bowditch American Practical Navigator 1958 Hydrographic Office No. 9 Appendix S. Unfortunately, the first three digits are not adequate in describing the specific port location for many regions. As an example of this inadequacy, the index numbers for the San Francisco

TABLE VII. VESSEL LENGTH CATEGORIES

CODE	LENGTH, FEET
1	65 or under
2	Over 65 to less than 100
3	100 to less than 200
4	200 to less than 300
5	300 to less than 400
6	400 to less than 500
7	500 to less than 600
8	600 to less than 700
9	700 and over
(-)	Unknown

TABLE VIII. LOCATION INDEX NUMBERS

INDEX NO.	LOCATION
16600	San Francisco Bay
16610	Alcatraz Island, Light
16620	San Francisco
16630	Redwood City
16640	Alameda
16650	Oakland
16660	Richmond
16670	Port Chicago
16680	Stockton
16690	Vallejo

Bay Area are shown in Table VIII. Prior to Fiscal Year 1976, a casualty occurring in any of the locations would have been recorded as "166," the first three digits. To determine the exact location, it is necessary to review the microfilm record for specific casualties.

In Fiscal Year 1976, the Coast Guard began computer coding the second through fourth digits of the Bowditch index number and therefore provided a readily accessible and specific record of port locations. These computer codes have been used in preference to the microfilm records because they saved time in identifying collisions relevant to this research.

<u>Cause</u>

The cause of the casualty is important when evaluating the effectiveness of various collision reduction methods. The three main inputs which are made into the computer tapes in regard to the cause of the casualty are primary cause, amplifying cause of collision, and additional contributing factors. Table IX lists the primary causes that can be entered. An amplifying factor for the primary causes can also be entered. For example, Table X shows the amplifying factors available when the primary cause is due to personnel fault. The categories of area of causal connection and additional contributing factors include details such as the specific Rules of the Road that were violated.

<u>Visibility</u>

Visibility is one of several quantitative factors that is recorded. Without imposing restrictions, low visibility is obviously a more dangerous condition than unlimited visibility. Certain Rules

TABLE IX. CAUSE OF CASUALTY

CODE	DESCRIPTION
A	Personnel fault, state pilot
B	Personnel fault, federal pilot
C	Personnel fault, foreign pilot, foreign master
D	Personnel fault, licensed personnel
E	Personnel fault, certificated personnel
F	Personnel fault, unlicensed, uncertified personnel
G	Personnel fault, unlicensed pleasure boat
H	Personnel fault, all others
I	Calculated risk
J	Storms, heavy weather
K	Adverse weather
L	Unusual currents
M	Sheer, suction, bank cushion
N	Depth less than charted
O	Restricted maneuvering room
P	Structural failure
Q	Equipment failure - normal wear
R	Equipment failure - material fault
S	Equipment failure - design
T	Equipment failure - personnel fault
U	Unseaworthy
V	Unknown/other
W	Fault of other vessel/personnel
Y	Floating debris, submerged object
Z	Insufficient horsepower/inadequate tug assistance

TABLE X. AMPLIFYING CAUSE OF CASUALTY

CODE	DESCRIPTION
A	Violation of Rules of the Road
B	Structural failure resulting from improper loading
C	Improper or failure to post lookout
D	Structural failure due to excessive speed in heavy weather
E	Not used
F	Not used
G	Misjudged effects of wind, current or speed
H	Improper reliance on floating aids to navigation
I	Not used
J	Failure to ascertain navigation position
K	Failure to utilize all available navigational equipment
L	Vessel sheared
M	Failure to align tow properly
N	Lack of local knowledge
O	Not used
P	Inexperienced personnel
Q	Maneuvered without proper assistance
R	Carelessness or inattention (sleep)
S	Improper corrective procedures
T	Poor seamanship resulting in fouled wheel or shaft
U	Improper determination of height of tide
V	Inadequate control of assisting vessel
W	Improper mooring or towing
X	Improper safety precautions
Y	Improper securing or rigging
Z	Not otherwise classified

of the Road are intended to reduce collision risk in times of low visibility (e.g., fog signals, speed reduction). However, other factors, such as the demand to meet certain schedules, may result in some vessels violating the Rules of the Road, thereby increasing the risk of collison.

Waterborne Commerce of the United States

The primary source for transit or traffic data used in this study is the U. S. Army Corps of Engineers' annual publication Waterborne Commerce of the United States. It presents detailed statistics on ship traffic in U. S. ports, harbors, waterways, and canals. Table XI gives an example of vessel trips and drafts reported for San Francisco in 1976. Vessel trips and drafts are recorded for the following category vessels: self-propelled passenger and dry cargo, self-propelled tanker, self-propelled towboat or tugboat, non self-propelled dry cargo, and non self-propelled tanker.

Statistics are given for both inbound and outbound directions. Appendix A shows that the draft of a particular type of vessel can be used to approximate its length. This approximation allows the correlation of transits and ship lengths for various types of vessels. Transit statistics are generated by doubling the inbound trips to give the total traffic numbers.

The Waterborne Commerce publication omits fishing and naval vessel transits. There are at least two ways to compensate for the lack of fishing boat and naval vessel traffic information. The first is not to correlate fishing and navy vessel casualty information

TABLE XI. SAN FRANCISCO, CALIF., DISTRICT TRAFFIC STATISTICS

Harbor or Waterway	Inbound						Outbound					
	Self-Propelled Vessels			Non Self-Propelled Vessels			Self-Propelled Vessels			Non Self-Propelled Vessels		
Draft (feet)	Passenger and Dry Cargo	Tanker	Towboat or Tugboat	Dry Cargo	Tanker	Total	Passenger and Dry Cargo	Tanker	Towboat or Tugboat	Dry Cargo	Tanker	Total
San Francisco Harbor, Calif,				Inbound						Outbound		
37	1					1	4					4
36	1					1	5					5
35	3					3	7	2				9
34	4	1				5	5	1				6
33	3	1				4	4	1				5
32	8					8	12	2				14
31	13	3				16	13	4				17
30	27	3				30	28	2				30
29	49	2				51	39	2				41
28	54	1				55	77					77
27	49	2				51	40	1				41
26	66	3				69	68	5				73
25	66					66	59	4				63
24	61	7				68	53	2				55
23	52	1			1	54	62	1				63
22 and less	804	14	3,339	1,018	203	5,378	785	10	3,339	1,018	205	5,357
Total	1,261	38	3,339	1,018	204	5,860	1,261	37	3,339	1,018	205	5,860

with fishing and naval vessel traffic. The second is to estimate the amount of their traffic. Since estimating traffic would be subjective and difficult to do or obtain and validate, the first approach was selected.

The net effect of not correlating fishing and naval vessel transits with fishing and naval vessel casualties is that the model cannot be used to predict collisions for these types of vessels. The influence of fishing and naval vessels on predicting collisions for other types of vessels is included in the model since collision rate values for other types of vessels were derived based upon historical results that included the presence of fishing and naval vessel traffic.

Port Series

The Port Series reports published by the United States Army Corps of Engineers include data on specific port parameters that could be useful in identifying port factors which contribute to collisions. Information available in the reports includes the number of piers, wharfs and docks, berthing space and weather conditions. In Section VI, a port factor contribution to collisions is identified based upon the parameter "average traffic per day multiplied by berthing space." This parameter is indicative of a port's activity level and therefore is useful in predicting collisions.

Data Shortcomings

This research was hampered somewhat by data shortcomings. The major limitation imposed by the data shortcomings was that port and ship factor coefficients had to be associated with grouped attributes,

as opposed to being able to identify uniquely the contribution of each individual attribute. Even though the grouping of attributes did not significantly affect the ability of the Collision Prediction Model to identify collision trends and approximate the number of collisions for various ports, this section elaborates on some of the more important shortcomings.

Coast Guard Vessel Casualty Records

1. Reporting periods for transit data and collision data are not the same. As noted in Section V, an assumption is made that the number of transits during a fiscal year can be correlated with casualty data for the calendar year. Although the assumption is reasonable, data for the same 12-month period would yield more accurate results.
2. Specific location is not reported prior to FY'76.
3. Information such as the type of equipment installed in the ship, the operating status of such equipment, and the speed of the ship when in extremis (extreme danger) is incomplete. Also missing from the data is an indication of whether or not a vessel was under port control or a port advisory system.
4. Several errors occur when computer coding the data. A common error is to report length in meters and be coded on the computer tapes in feet. In addition, the computer programmer occassionally enters an incorrect location code. This error is prone to happen, since the Coast Guard form for reporting casualties does not incorporate the code

system for pinpointing location, but instead provides only for a general description of locale.

5. Certain parameters such as length and time lack specific numerical values. As noted in Section V, assumptions were made as to midpoint values (e.g., midpoint length of 550 feet used for ship casualties between 500 and 600 feet).

U. S. Army Records - Waterborne Commerce of the United States

1. Foreign vessel transits are included in the reported transit data. However, it cannot be determined from the annual publication which transits are related to foreign vessels and which transits are associated with United States vessels. Accordingly, nationality could not be identified as a significant parameter in collisions since foreign transits could not be isolated.

2. The Army reports transits for five categories of vessels: 1) passenger and dry cargo, 2) tanker, 3) towboat or tugboat, 4) non self-propelled dry cargo, and 5) non self-propelled tanker. The Coast Guard uses 29 categories in their Vessel Casualty Records (See Table III). It would be most helpful for future research if the transit data were reported for the Coast Guard vessel categories.

3. In some areas, there is an overlap of reported transits. For example, transits are reported for Sacramento River, Sacramento River Deepwater Ship Channel, and Sacramento Harbor. The same vessel transiting up the Sacramento River to Sacramento would be listed separately under each of the

three areas listed. The reporting requirements are defined by the Corps of Engineers and heavily based upon Army Port Projects. Care must be exercised to avoid duplicate counting of transits.

Port Series

1. Port Series reports do not exist for all Pacific Coast Ports. Lack of this information prevented determination of port factor contributions for certain Pacific Coast ports (e.g., Skagaway, Wrangell, Kodiak).
2. Port parameter data may not be up-to-date. Certain volumes of the port series have not been updated in ten years (e.g., San Diego, Los Angeles, and Long Beach).

Data Shortcoming Summary

Although several shortcomings exist with the data, they are not significant enough to invalidate this research. The data deficiencies can be grouped into two general categories: data shortcomings which limit the scope of the research and data shortcomings which can be ignored or circumvented by analysis. An example of limited scope is the lack of reported transits for fishing and naval vessels. The net effect is that the model cannot be used to predict collisions for these types of vessels. Other examples of data shortcomings that result in limiting the scope of the research are:

1. Lack of specific information regarding status of ship equipment installed and operating status. The impact is that ship equipment could not be analyzed individually as to its contribution to avoiding/causing ship collisions.

2. Nonexistence of port series reports for certain ports which resulted in certain ports not being evaluated.

3. Failure of the Waterborne Commerce reports to specify transits for the more detailed ship-type categories used by the Coast Guard in their Vessel Casualty Records, including foreign vessels. This resulted in the grouping of ship-types (e.g., passenger/cargo, tankers).

Examples of data shortcomings that required additional analysis to ensure accuracy or were not considered significant are:

1. Lack of reporting transits and collisions for the same time periods. (Not considered significant.)

2. Errors when reporting or computer coding the data. (Additional analysis used.)

3. Overlap of reported transits. (Additional analysis used.)

4. Port parameter data that may be out of date. (Not considered significant.)

5. Lack of specific numerical values for certain parameters such as length. (Additional analysis used.)

6. Location not specifically reported prior to FY'76. (Not considered significant.)

General recommendations to the agencies responsible for the data collection and reporting (Coast Guard and Army Corps of Engineers) are to: a) include additional detail or new statistics; b) devise methods which would minimize reporting and coding errors; c) provide flexibility so that calendar year and fiscal year data can be correlated; and d) update reports when significant changes occur.

One specific recommendation in regard to the Waterborne Commerce publication would be to tabulate transits as a function of Net Register Tons for the Coast Guard Vessel Categories of Table III. This tabulation could be listed in addition to the reporting of drafts. Availability of transit information as a function of ship-type and size would be most useful in maritime research. Little additional effort would be required by the Army Corps of Engineers since Net Register Tons are required to be listed on the forms from which che Waterborne Commerce statistics are generated (Corps of Engineers, Department of the Army Eng. Form 3925).

V. ANALYSIS AND EVALUATION OF DATA

Section IV described the major sources of ship usage and collision data used in this research. Section V describes the methodology, mathematical techniques and results of the data evaluation. Computer systems were used extensively to sort, analyze statistically, trend fit the data, and derive equations for the mathematical model.

Project Find

The only feasible method to sort, evaluate and analyze statistically the extensive casualty information is with the aid of computer systems. The Coast Guard transferred its stored information onto supplied tapes in order to facilitate this research. The computer tapes contain approximately 40,000 vessel entries for all types of casualties. Each vessel entry is represented by 80 BITS of data. Thus, the vessel casualty data contain over 3,000,000 BITS of data. In order to analyze the extensive data, a computer subsystem program entitled Project Find was used. Project Find is a management information system on the Dartmouth Time Sharing System. A few elementary terms of Project Find are defined:

DATA BASE - A structured collection of information or data. The data base can be considered as a two-dimensional array or matrix. Each row in the data base represents one vessel involved in a collision (entity) and each column represents some attribute or characteristic of the entity.

ATTRIBUTE - A characteristic or property of the entity (e.g.,

length, location, visibility, collision type). The value of an attribute can be either numeric (consisting of digits), such as dollar losses, or string valued (including some alphabetic characters), such as location or cause of casualty. The attributes used in this analysis are listed in the Appendix Table B-1.

The data base provided by the Coast Guard was modified as follows to permit expanded statistical access and identification on the Dartmouth Time Sharing System:

1. The addition of a unique identifier for each entity.
2. Conversion of seven string attributes to numeric attributes to allow statistical evaluation. This conversion allowed use of the computer statistical subroutines described later in this section, since numeric values are required for the statistical applications.

As a result of these changes, the 80 BITS of data available on the Coast Guard data were expanded to 101 BITS of data. Table B-2 in the Appendix describes the attributes and meanings for one vessel involved in a collision. The Coast Guard's coding instructions for commercial vessel casualties are contained in Reference 3.

FSTAT (Find Statistics Package)

FSTAT is a program which applies statistical analysis techniques to a FIND data base. FSTAT communicates with FIND in such a manner that FIND and FSTAT commands may be freely intermixed, thus providing a combined data base management and statistical analysis capability.

Some of the more important commands in FSTAT are as follows:

STATISTICS - The statistics command is used to produce representative statistics on a list of numeric variables. Included are maximum value, minimum value, range, sum, sum of squares, mean, median, variance, standard deviation, standard error of the mean, and the coefficient of variance.

CORRELATE - The correlate command produces an integrated correlation matrix of a list of numeric variables. Missing data for any observation exclude the entire observation from the analysis.

HISTOGRAM - The histogram command plots the histogram of any string or numeric variable. A string variable is defined to include alpha-numeric designators or numeric designators that do not represent quantitative data.

Example of FIND/FSTAT

Since the commands and outputs of FIND and FSTAT are freely intermixed, an example is given to show their usage without designating which sub-program produced the results. The fiscal year 1976 (15 months)* Coast Guard computerized casualty data were extensively used in developing the mathematical model. The data base contains 4,261 vessels involved in collisions. Table B-3 shows the evaluation of all 4,261 vessel collisions using the histogram, statistics, and correlate commands. Similar analysis was conducted and is available for those vessels involved in Pacific Ocean collisions. Analysis was also done for individual ports such as Long Beach, Seattle, Tacoma, San

*During 1976, the start of the fiscal year was moved from 1 July to 1 October. Therefore, FY'76 covered a 15-month interval.

Francisco, etc. In addition, the FIND system allows new variables to be defined. Two variables that are defined and statistically reported in Table B-3 are total dollars (DOLTOT) which is the sum of losses to vessel, cargo, and property, and total killed (TOTKIL) which is the sum of passengers, crew, workmen, and others killed.

Length and Draft Correlation

The purpose of correlating length and draft for various types of ships is to allow collision data to be correlated with the traffic data reported in the Waterborne Commerce of the United States. The collision data recorded by the Coast Guard include length and type of ship. The Waterborne Commerce publication reports transits as a function of draft for the following types of ships: passenger and dry cargo, tanker, towboat or tugboat, and non self-propelled cargo and tanker barges. Therefore, by correlating length and draft for these types of vessels, collision data can be correlated with traffic data.

A study was accomplished by Sciences Application, Inc. (Reference 4) which included a correlation between draft and waterline length. Figures A-1 through A-6 in the Appendix show the correlation and mathematical equations for passenger, cargo, tanker, tug and barges. The equations from Figures A-1 through A-6 were used to calculate drafts for the following ship length intervals: <65, 65<100, 100<200, 200<300, 300<400, 400<500, 500<600, 600<700, and ≥700 feet. Table XII shows this correlation of length and draft. The Table XII column entitled "Rounded" lists the draft values used when determining the number of transits for various type ships. A

TABLE XII. DRAFT VERSUS LENGTH FOR VARIOUS TYPE SHIPS (FEET)

Ship Length (feet)	Tug		Tanker		General			Barge		
	Draft	Rounded	Draft	Rounded	Passenger Draft	Cargo Draft	Rounded	Ocean Draft	Tank Draft	Rounded
65	7.9	$\leq$7	7.6	$\leq$7	3.8	7.8	$\leq$4	3.5	3.5	$\leq$3
65<100	7.9-12.4	8-12	7.6-9.4	8-9	3.9-5.7	7.9-10.3	5-7	3.6-5.4	3.6-5.3	4-5
100<200	12.5-25.4	13-25	9.5-14.4	10-14	5.8-10.9	10.4-16.1	8-13	5.5-10.8	5.4-10.5	6-10
200<300	N/A	N/A	14.5-19.5	15-19	11.0-16.0	16.2-21.0	14-18	10.9-16.2	10.6-15.7	11-16
300<400	N/A	N/A	19.6-24.6	20-24	16.1-20.4	21.1-25.3	19-22	16.3-21.6	15.8-20.8	17-21
400<500	N/A	N/A	24.7-29.7	25-29	20.5-25.7	25.4-29.2	23-27	21.7-27.0	20.9-25.8	22-27
500<600	N/A	N/A	29.8-34.7	30-34	25.8-30.5	29.3-32.9	28-31	>27.0	>25.8	$\geq$28
600<700	N/A	N/A	34.8-39.8	35-39	30.6-35.2	33.0-36.3	32-35	N/A	N/A	N/A
$\geq$700	N/A	N/A	>39.8	$\geq$40	>35.2	>36.3	$\geq$36	N/A	N/A	N/A

"Rounded" value is necessary for two reasons. First, the Waterborne Commerce reports drafts in one foot increments, and therefore the "Rounded" values were selected as integer values. Second, the Waterborne Commerce groups certain category vessels such as passenger and dry cargo vessels and therefore an average or "Rounded" value was selected. Table XIII gives an example of tabulating transits for one port, which in this case is San Francisco. Tables XIV and XV summarize this type of evaluation for the Pacific Coast ports during 1975.

Figures A-1 through A-6 are for vessels with full load drafts. Some vessels, such as tankers, may enter port loaded and leave with much less draft. Therefore, if both inbound and outbound drafts are used to tabulate traffic, a vessel may be listed in two different length categories. To avoid this error, only inbound transits are used to tabulate traffic and the results doubled to give total transits. Some error still remains in tabulating traffic since vessels are not always fully loaded when entering ports. This error probably results in inflated traffic estimates for the smaller ship length categories. The magnitude of this error is unknown; however, underestimating traffic for the largest ship length grouping by 50% would not affect the conclusions of this research. This is based on the fact that collisions per transit for the largest ship length category is approximately 60 times greater than for the smallest ship length category.

TABLE XIII. TABULATION OF TRANSITS (1-WAY) FOR SAN FRANCISCO

LOCATION: SAN FRANCISCO BOWDITCH CODE: 16620 YEAR: 1975

Draft	Passenger/ Cargo	Length Category (feet)	Tanker	Length Category (feet)	Towboat Tugboat	Length Category (feet)	Non-Self Propelled	Length Category (feet)	Total (1-Way)
41	0		0	≥700 (0)	None	None	None	None	
40	0		0						
39	0		1						≥700 feet 4
38	0	≥700 (4)	0	6 <700 (2)					
37	1		1						
36	3		0						
35	1		0						
34	4	6 <700 (25)	1						6 <700 feet 27
33	5		0	5 <600 (4)					
32	15		3						
31	17		0						
30	28	5 <600 (195)	0						5 <600 feet 199
29	54		1						
28	96		1						
27	68		2	4 <500 (8)					
26	58		0						4 <500 ft 325
25	71	4 <500 (317)	2						
24	65		0						
23	55		0	<400 (11)	None	None	None	None	
22 or less	787	<400 (787)	11		5548	<400	662	<400	< 400 feet 7008
									TOTAL 7563

TABLE XIV. HAWAII AND ALASKA 1975 TRAFFIC (2-WAY)

Location	All Traffic					Traffic < 400 feet					Traffic 400<500 feet				Traffic 500<600 feet			Traffic 600<700 Feet			Traffic ≥700 Feet		
	Total	Passenger Cargo	Tanker	Tugboat Towboat	Non self-propelled	Total	Passenger Cargo	Tanker	Tugboat Towboat	Non self-propelled	Total	Passenger Cargo	Tanker	Non self-propelled	Total	Passenger Cargo	Tanker	Total	Passenger Cargo	Tanker	Total	Passenger Cargo	Tanker
Honolulu	16,474	8,216	194	4,806	3,258	15,124	7,112	30	4,806	3,176	416	307	32	82	727	604	118	212	198	14	0	0	0
Hilo	1,326	254	48	554	470	1,180	156	30	554	440	98	52	16	30	30	28	2	18	18	0	0	0	0
Kawaihae	598	24	10	322	242	578	8	6	322	242	12	10	2	0	4	2	2	4	4	0	0	0	0
Kahului	1,718	384	36	696	606	1,570	322	10	696	542	114	30	20	64	24	22	2	10	10	0	0	0	0
Kanakahai	2,244	0	0	1,182	1,062	2,176	0	0	1,182	994	68	0	0	68	0	0	0	0	0	0	0	0	0
Nawiliwili	1,014	264	8	406	336	990	240	8	406	336	6	6	0	0	14	14	0	4	4	0	0	0	0
Hawaii	23,374	9,142	296	7,966	5,974	21,612	7,838	84	7,966	5,710	714	400	70	244	794	670	124	248	234	14	0	0	0
Ketchikan	11,026	8,474	92	1,262	1,198	10,932	8,436	36	1,262	1,198	56	26	24	0	44	12	32	0	0	0	0	0	0
Wrangell	6,430	5,190	0	718	522	6,406	5,166	0	718	522	16	16	0	0	8	8	0	0	0	0	0	0	0
Anchorage	2,034	934	162	580	358	1,510	582	24	580	324	202	120	48	34	304	230	74	16	0	16	2*	2*	0
Kodiak	3,770	3,326	72	352	20	3,642	3,216	56	352	18	112	100	10	2	16	10	6	0	0	0	0	0	0
Sitka	1,930	500	4	916	510	1,848	422	0	916	510	58	54	4	0	24	24	0	0	0	0	0	0	0
Skagway	1,248	1,122	22	64	40	1,192	1,068	20	64	40	50	48	2	0	6	6	0	0	0	0	0	0	0
Valdez	2,450	678	174	1,186	612	2,348	474	108	1,186	580	68	4	32	32	34	0	34	0	0	0	0	0	0
Seward	1,612	1,306	18	142	146	1,566	1,260	18	142	146	38	38	0	0	8	8	0	0	0	0	0	0	0
Alaska	30,503	21,330	544	5,220	3,406	29,444	20,624	262	5,220	3,338	594	406	120	68	444	298	146	16	0	16	2	2	0

* 2 Transits adjusted from 600<700 ft. category to match collision data.

TABLE XV. SOUTHERN CALIFORNIA, SAN FRANCISCO BAY AND PUGET SOUND 1976 TRAFFIC (2-WAY)

Location	All Traffic: Total	All Traffic: Passenger /Cargo	All Traffic: Tanker	All Traffic: Tugboat Towboat	All Traffic: Non self-Propelled	Traffic < 400 Feet: Total	Traffic < 400 Feet: Passenger /Cargo	Traffic < 400 Feet: Tanker	Traffic < 400 Feet: Tugboat Towboat	Traffic < 400 Feet: Non self-Propelled
San Diego	3,158	2,132	68	528	430	2,882	1,912	12	528	430
Long Beach	47,546	23.964	972	14,142	8,468	46,514	21,684	220	14,142	8,468
Los Angeles	25,974	3,308	1,672	17,006	3,988	22,664	1,160	534	17,006	3,964
Southern California	76,678	29,404	2,712	31,676	12,886	70,060	24,756	766	31,676	12,862
San Francisco	15,126	2,656	50	11,096	1,324	14,016	1,574	22	11,096	1,324
Redwood	558	2	16	310	230	548	0	8	310	230
Oakland	15,618	3,976	56	10,180	1,406	13,236	1,624	30	10,180	1,402
Richmond	12,262	946	1,176	8,062	2,078	11,294	812	342	8,062	2,078
Stockton	786	254	26	264	244	666	156	6	264	240
S.F. Bay Area	44,350	7,834	1,322	29,912	5,282	39,760	4,166	408	29,912	5,274
Pt. Angeles	5,282	330	20	3,656	1,276	5,174	240	4	3,656	1,274
Pt. Townsend	10,718	5,366	8	2,822	2,522	10,706	5,362	0	2,822	2.522
Seattle	113,910	68,250	316	32,802	12,542	112,176	66,832	96	32,802	12,466
Tacoma	30,976	14,168	116	14,486	2,226	30,314	13,618	38	16,486	2,172
Olympia	1,370	64	0	1,218	88	1,350	44	0	1,218	88
Everett	18,478	2,244	8	14,756	1,472	18,320	2,114	0	14,756	1,452
Anacortes	32,898	28,184	240	3,706	770	32,716	28,172	96	3,704	744
Bellingham	14,294	5,352	30	7,726	1,186	14,222	5,302	8	7,726	1,186
Puget Sound	227,926	123,938	738	81,168	22,082	224,978	121,684	242	81,168	21,884

Location	Traffic 400-500 Feet: Total	Traffic 400-500 Feet: Passenger /Cargo	Traffic 400-500 Feet: Tanker	Traffic 400-500 Feet: Non self-Propelled	Traffic 500-600 Feet: Total	Traffic 500-600 Feet: Passenger /Cargo	Traffic 500-600 Feet: Tanker	Traffic 600-700 Feet: Total	Traffic 600-700 Feet: Passenger /Cargo	Traffic 600-700 Feet: Tanker	Traffic ≥700 Feet: Total	Traffic ≥700 Feet: Passenger /Cargo	Traffic ≥700 Feet: Tanker
San Diego	142	128	14	0	90	52	38	38	36	2	6	4	2
Long Beach	1,392	1,160	132	0	1,164	898	266	344	204	140	232	18	214
Los Angeles	1,490	1,308	258	24	1,170	712	458	378	118	260	172	10	162
Southern California	3,024	2,596	404	24	2,424	1,662	762	760	358	402	410	32	378
San Francisco	650	634	16	0	398	390	8	54	50	4	8	8	0
Redwood	6	2	4	0	4	0	4	0	0	0	0	0	0
Oakland	1,268	1,252	12	4	886	872	14	222	222	0	6	6	0
Richmond	396	94	300	0	488	38	450	74	2	72	12	0	12
Stockton	80	62	14	4	38	34	4	2	2	0	0	0	0
S.F. Bay Area	2,398	2,044	346	8	1,816	1,336	480	352	276	76	26	14	12
Pt. Angeles	48	44	2	2	32	22	10	14	10	4	14	14	0
Pt. Townsend	10	2	8	0	2	2	0	0	0	0	0	0	0
Seattle	1,126	946	84	96	460	370	90	146	102	44	2	0	2
Tacoma	408	332	22	54	156	128	28	70	46	24	28	24	4
Olympia	16	16	0	0	4	4	0	0	0	0	0	0	0
Everett	102	80	2	20	24	24	0	14	8	6	18	18	0
Anacortes	62	8	28	26	40	2	38	32	2	30	48	0	48
Bellingham	42	30	12	0	20	10	10	8	8	0	2	2	0
Puget Sound	1,814	1,650	158	198	738	562	176	284	176	108	112	58	54

VI. DERIVATION OF MATHEMATICAL MODEL FOR PREDICTING COLLISIONS

As discussed in Section III, the number of collisions for a particular time period for any port can be characterized as a function of ship factors, port factors and the degree of exposure to collision situations.

In Section III, equation (3), the generalized mathematical model is given as:

$$\text{Number of collisions} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{z=1}^{q} \lambda_{ij \cdots z} T_{ij \cdots z}$$

where

$\lambda_{ij \cdots z}$ = collision rate for the ij ⋯ z subcategory.

$T_{ij \cdots z}$ = number of transits for the ij ⋯ z subcategory.

If we distinguish between the ship and port factors, we can express λ as:

$$\lambda = Y_{\substack{\text{ship}\\\text{factor}}} \; Y_{\substack{\text{port}\\\text{factor}}} = Y_{SF} \; Y_{PF}$$

where Y represents the ship and port contributors.

Two ship factor components (ship length and ship-type) and two port factor components (port traffic and port magnitude of activity) are identified and quantified to form the mathematical basis for ship and port factors. In conjunction with transits, these numerically derived coefficients provide a basis for predicting collisions. The generalized Collison Prediction Model (CPM) is given as:

$$\text{Number of collisions} = \sum_{i=1}^{5} \sum_{j=1}^{3} \sum_{p=1}^{21} \lambda_{ijp} T_{ijp} = \underbrace{\lambda_i \ \pi_{ij}}_{\substack{\text{ship}\\ \text{factors}}} \ \underbrace{\pi_p}_{\substack{\text{port}\\ \text{factors}}} \ \underbrace{T_{ijp}}_{\substack{\text{exposure}\\ \text{criteria}}} \tag{6}$$

where

λ_{ijp} = collision rate for ship length category i, ship type j and port p.

T_{ijp} = transits for length category i, ship type j and port p.

Evaluation of equation (6) shows that the collision rate, λ_{ijp}, is comprised mathematically of ship and port factors. The derivation of the quantitative values for these ship and port factors is given later in this section. The two port factor components, port traffic and port magnitude of activity, can be combined mathematically to give a single port coefficient, π_p, as shown in equation (6).

The Collision Prediction Model can also be expressed as:

For ship length i

$$\text{Number of collisions} = \underset{\substack{\uparrow\\ \text{collision}\\ \text{rate}}}{\lambda} \quad \underset{\substack{\uparrow\\ \text{ship}\\ \text{type}}}{\pi_j} \quad \underset{\substack{\uparrow\\ \text{port}}}{\pi_p} \quad \underset{\substack{\uparrow\\ \text{transits}}}{T_{jp}}$$

The total number of predicted collisions is obtained by adding the number of collisions predicted for each ship length interval.

The development of the Collision Prediction Model is based on either of the following criteria: 1) predicted collisions should be within two collisions of historical results or 2) predicted

collisions should be within 25 percent of historical results for ports with more than eight collisions during the evaluation period. These criteria were selected based upon objective judgment on the accuracy required to match data upon which the CPM is derived.

The remainder of this section describes the data base used in deriving the model, develops mathematical equations for ship and port factors, relates the mathematical equations to each other and develops a detailed model for predicting collisions.

Data Base for Generation of Model

Since location of the collision is of primary importance in this research and since specific location codes were incorporated for the first time in the Coast Guard's Fiscal Year 1976 casualty records, the 15-month Fiscal Year 1976 casualty records are used to generate the ship and port factors coefficients. Validation of the model is accomplished using both Fiscal Year 1976 and 1977 casualty data.

Exposure Criteria

Exposure criteria are used to define quantitatively collision situations. A ship is exposed to a potential collision whenever it leaves or enters a harbor. Therefore inbound and outbound transits are defined as the exposure criteria. Mathematically, $T_{ij\cdots z}$ in equation (5) represents the transits for each subcategory $ij\cdots z$.

Ship Factors (Y_{SF})

To generate the ship factor mathematical equations, significant parameters are identified and equations fitted to model the effects of these significant parameters on ship collisions.

Ship factors include such parameters as size, type, age, equipment, speed, training and personnel qualification. This list is not inclusive but rather indicates the kinds of parameters that can be associated with a ship and which may contribute to collisions. The following approach is used to generate the equations associated with ship factors:

1) Ship collisions as a function of significant parameters are investigated to determine if a mathematical trend can be established (for example, as a function of ship size).
2) Within the trend established, further delineation of significant parameters is investigated (for example, the effect of different types of ships for various ship sizes).
3) Where data may not be sufficient to delineate further significant parameters within a trend, a means for incorporating their future identification and values is provided for in the model (for example, the model allows for the effect of improvement in ship equipment such as collision avoidance radars).
4) Finally, the equations are validated by comparing model predictions with historical data.

Ship Size

Ship size is the first parameter selected to determine if a trend of collisions as a function of ship size can be established. Ship size was selected because larger ships would appear to have a higher likelihood of collision since they have a larger turning radius and greater momentum and thus require more time to slow and stop.

Since there are many more small ships than large ships, looking strictly at the number of collisions as a function of ship size would provide a distorted viewpoint. In order to provide a common baseline for comparison, the normalized parameter of collisions per transit is used; that is, by dividing the number of collisions for various size ships by the number of transits for the same size ships, a collision statistic on a per transit basis is determined. This approach allows a determination of collision risk versus ship size on an individual transit basis.

Table XVI lists the total number of transits for five major regions on the Pacific Ocean: Southern California, San Francisco Bay, Puget Sound, Alaska and Hawaii. The following ports are included in the regional groups: San Diego, Long Beach, Los Angeles, San Pedro, Wilmington, San Francisco, Redwood City, Oakland, Alameda, Richmond, Stockton, Port Angeles, Port Townsend, Seattle, Tacoma, Olympia, Everett, Anacortes, Bellingham, Honolulu, Hilo, Kawaihae, Kahului, Kanakakai, Nawiliwili, Ketchikan, Wrangell, Anchorage, Kodiak, Sitka, Skagaway, Valdez and Seward. These ports represent the Pacific Ocean ports for which detailed transit information is available from the U. S. Army's publication Waterborne Commerce of the United States.

The transits listed in Table XVI are for calendar year 1975. A comparison of traffic data reported in the Waterborne Commerce of the United States for calendar years 1975 and 1976 shows close agreement. Therefore, the following assumptions are made in regard to the use of

TABLE XVI. TRANSITS FOR CALENDAR YEAR 1975 (2-WAY) - ALL SHIPS

	Transits for Ship Length Intervals				
Region	< 400 feet	400 < 500 feet	500 < 600 feet	600 < 700 feet	≥ 700 feet
Southern California	70,060	3,024	2,424	760	410
San Francisco	39,760	2,398	1,814	352	26
Puget Sound	224,978	1,814	738	284	112
Hawaii	21,618	714	794	248	0
Alaska	29,444	594	444	18	2
12 Month Total	385,860	8,544	6,214	1,662	550
15 Month Total	482,325	10,680	7,767	2,077	687

calendar year 1975 data:

1) Calendar years 1975 and 1976 transit data are approximately the same.

2) Since the collision data cover the 15-month Fiscal Year 1976 period, the transits for 12 months can be adjusted by a factor of 1.25 to determine transit data for a 15-month period.

3) The adjusted 15-month transit data based on 1976 calendar data can be correlated with the 15-month Fiscal Year 1976 casualty data.

Table XVII lists the collisions by location and ship length for the geographical regions listed above. Appendix C describes the analysis used to arrive at the collision statistics of Table XVII. Omitted from consideration were fishing and naval vessel collisions and those occurring outside a 5 nautical mile radius of the port entrance.

The elimination of fishing and naval vessels, discussed in Section IV, is based upon the lack of reported transit data for these vessels. A criterion of a 5 nautical mile radius from the port entrance was imposed in order to be consistent with the scope of this research. A 5 nautical mile criterion is not considered restrictive since the great majority of collisions occur in or around ports. Figure C-1 in Appendix C illustrates the boundaries established for counting collisions in San Francisco Bay.

Vessels that were counted in the collision statistics include tugs that were attached to assist larger vessels in docking or

TABLE XVII. COLLISIONS FOR PACIFIC WATERS (FY'76) - ALL SHIPS

	Collisions for Ship Length Intervals				
Region	< 400 feet	400 < 500 feet	500 < 600 feet	600 < 700 feet	≥ 700 feet
Southern California	16	2	2	4	2
San Francisco	7	0	3	4	1
Puget Sound	36	4	5	1	2
Hawaii	12	1	0	3	2
Alaska	19	3	1	0	1
Total	90	10	11	12	8

undocking. Although each tug may not have been damaged in the accident, it is felt that the tug is part of the collision and therefore should be counted. Since tugs assisting other vessels and tugs towing or pushing barges represent a special circumstance, future research might want to analyze these collisions separately.

The results of correlating collisions per transit versus ship size are shown in Figure 2. This figure shows an increase in collisions on an individual transit basis as ship length increases. The results are based on more than 500,000 transits and 171 vessels involved in collisions. The figure also shows the actual data points and an exponential curve fit. The exponential fit was selected as representative of the trend of collisions on a per transit basis as a function of ship length, since it closely duplicates historical results.

To determine whether or not this trend holds true for smaller groupings of data, an analysis was performed for the following major regions of the Pacific Ocean: Southern California, Puget Sound, San Francisco Bay, Hawaii, and Alaska. The results are shown in Figure 3.

The increasing trend of collisions per transit as ship length increases is verified in all cases. It is assumed that the steep slope for Alaska is due to the additional hazards in navigating Alaskan waters such as ice, submerged objects such as logs, and the limited data available for large ships in Alaskan waters. A final determination to verify this trend was accomplished successfully using Fiscal Year 1970 data.

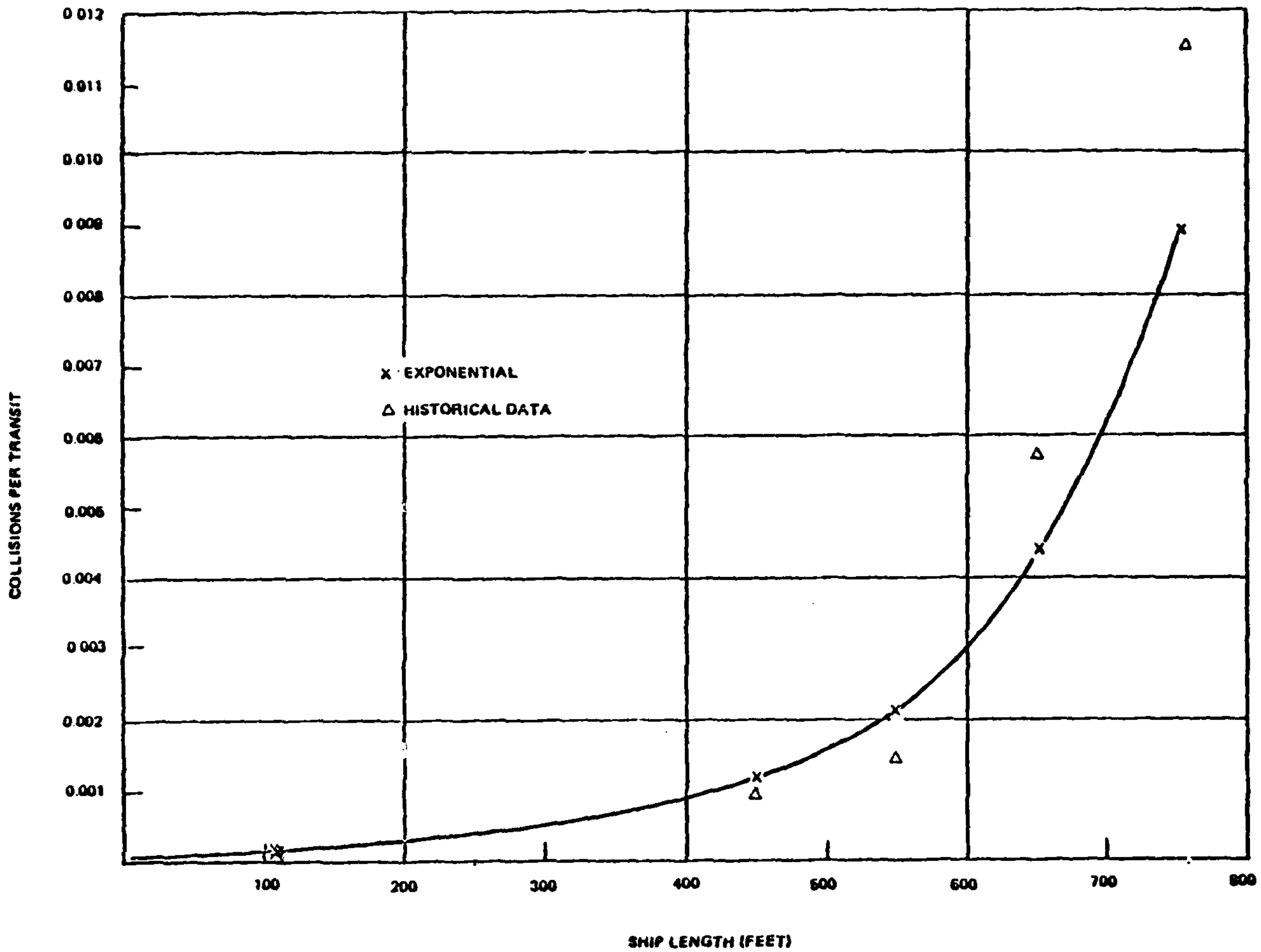


Figure 2. Collisions per Transit Versus Ship Size for Pacific Coast Ports

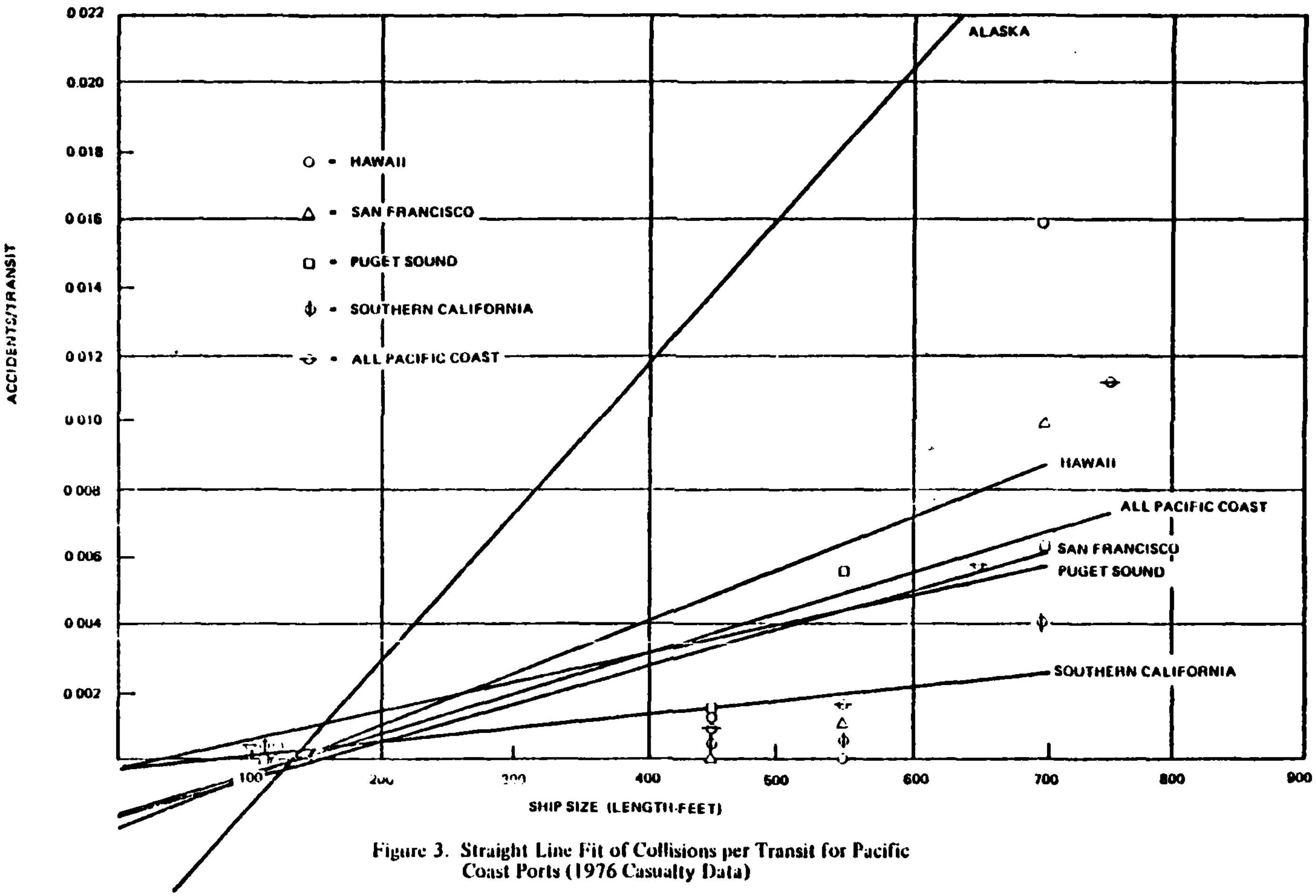


Figure 3. Straight Line Fit of Collisions per Transit for Pacific Coast Ports (1976 Casualty Data)

Since the exponential fit closely correlates with collision data, the mathematical relationship for ship factors can be represented by:

$$Y_{SF} = (a)\ (b)^{\text{length}} \tag{7}$$

Table XVIII shows the exponential fitting of the data and the derivation of the constants a and b. Since draft data are generally summed together for vessels with drafts of 18 feet or less, an exact accounting of transits as a function of ship length is not available for those ships with drafts less than 18 feet. Furthermore, since the likelihood of collision for smaller ships (up to 400 feet in length) is relatively constant and ships with drafts less than 18 feet fall into the less than 400 foot length category, ships less than 400 feet in length are grouped together. A midpoint of 120 feet, to cover the ship length interval of 0-400 feet, was selected based upon an average value for over 100 ships of this length category involved in collisions. For ships longer than 400 feet, ship length intervals of 100 foot increments were selected to be consistent with the 100 foot intervals reported in the Vessel Casualty Records. Thus ship length intervals of 0<400, 400<500, 500<600, 600<700 and equal to or greater than 700 feet were selected. For the derivation of the exponential fit, the midpoints of 450, 550, 650 and 750 feet were used in addition to the 120 foot midpoint described above. The midpoint of 750 feet for ships equal to or greater than 700 feet was selected for mathematical convenience and substantiated by evaluation of eight ships of this length category involved in collisions.

TABLE XVIII. COMPUTATION OF EXPONENTIAL FIT (ALL SHIPS)

Shiplength, X (Midpoint Feet)	Collisions Per Transit, Y	Log Y	X Log Y
120	0.000186596	- 3.729097263	- 447.5
450	0.000936330	- 3.028571252	-1362.9
550	0.001416248	- 2.848860691	-1566.9
650	0.005777564	- 2.238255235	-1454.9
750	0.011644833	- 1.933866735	-1450.4
2520	Not Used	-13.77865118	-6282.6

$$\text{Log a} = \frac{(\Sigma \text{ log Y})\ (\Sigma\ X^2) - (\Sigma\ X)\ (\Sigma\ X \text{ log Y})}{N\Sigma X^2 - (\Sigma X)^2}$$

$$= \frac{(-13.77865118)\ (1.5044 \times 10^6) - (2520)\ (-6282.6)}{(5)\ (1.5044 \times 10^6) - (6.3504 \times 10^6)}$$

$$= -4.179285456$$

$$\text{Log b} = \frac{N\Sigma X \text{ log Y} - (\Sigma X)\ (\Sigma \text{ log Y})}{N\Sigma X^2 - (\Sigma X)^2}$$

$$= \frac{(5)\ (-6282.6) - (2520)\ (-13.77865118)}{(5)\ (1.5044 \times 10^6) - (6.3504 \times 10^6)}$$

$$= 0.002824514$$

$$\text{Log } Y_{SF} = \text{Log a} + X \text{ Log b}$$

$$= -4.179285456 + (X)\ (0.002824514)$$

or

$$Y_{SF} = (0.000066178)\ (1.006524879)^X$$

A plot of Y_{SF} as a function of length is given in Figure 2 as represented by the exponential fit curve.

Methodology for Incorporating Other Factors

Identification of the trend of collisions as a function of ship size is significant in predicting collisions. However, it assumes that the effects of other ship factors are distributed evenly. If the prediction of collisions were the one objective of this research, identification of this trend solely as a function of ship size might be adequate. But, the methodology being developed must also incorporate the effects of other ship factors in order to predict the effectiveness of collision avoidance techniques. As an approximation, this capability is incorporated in the form of multiplicative factors as shown in:

$$Y_{SF} = \underbrace{(a)\ (b)^{\text{length}}}_{\lambda_i} (\pi_1\ \pi_2 \cdots \pi_n) \tag{8}$$

where

Y_{SF}, a, b are as defined previously.

λ_i = collision rate for category i (length).

$\pi_1\ \pi_2 \cdots \pi_n$ = multiplicative factors for other ship parameters such as age, type of vessel, equipment, training and personnel qualification.

length = length of ship.

Without the benefit of quantitative identification as to the effect of other ship factors, the multiplicative factors are initially assumed to be 1.0. This is consistent with saying that the effect of ship factors on the number of collisions can be modeled solely as a function of ship size. As analysis identifies the impact of various other ship factors, specific multiplicative factors can be used.

For example, assume that installing collision avoidance radars is estimated to result in a 10 percent reduction in collisions for ships 500 or more feet in length and a 5 percent reduction for all other ships. Multiplicative factors for ship equipment (π_{ij}) can then be assigned. The values of 0.9 for ships 500 or more feet in length and 0.95 for all other ships are assigned. The ship factor contribution is then

$$Y_{SF} = \underbrace{(a)\ (b)^{length}}_{\lambda_i}\ \pi_{ij} = \lambda_{ij} \tag{9}$$

where

λ_{ij} = collision rate for length category i and ship equipment j.

λ_i = collision rate for length category i.

π_{ij} = multiplicative factor to account for the contribution of ship equipment j in relation to ship length category i.

length = length of ship.

The ship equipment factor is shown numerically as:

a) <u>Ships 500 or more feet in length</u>

$$\begin{aligned} Y_{SF} &= (a)\ (b)^{length}\ \pi_{ij} \\ &= (0.000066178)\ (1.006524879)^{length}\ (0.9) \\ &= (0.000065668)\ (1.006524879)^{length} \end{aligned}$$

b) <u>Ships less than 500 feet in length</u>

$$\begin{aligned} Y_{SF} &= (a)\ (b)^{length}\ \pi_{ij} \\ &= (0.000066178)\ (1.006524879)^{length}\ (0.95) \\ &= (0.000062869)\ (1.006524879)^{length} \end{aligned}$$

Similar multiplicative factors possibly can be identified and

numerically assigned for such functions as age, type of vessel, training and personnel qualification.

Identification of Other Factors

Identification of other factors in addition to ship size is somewhat hampered by the lack of usage data to compare with collision data. As described in Section V, the Waterborne Commerce reports transit information for various draft ships for several types of vessels (passenger/cargo, tank ships, tugboats and towboats, and non self-propelled barges). Table XIII itemizes the transit data for the various type vessels as a function of vessel length. In order to correlate transit data with collision data, it is necessary to categorize the Coast Guard's 29 categories of vessels listed in Table III with the more general Waterborne Commerce categories. Table XIX shows this cross correlation.

Ship-Type

A similar analysis to that described in Section VI "ship size" was accomplished in regard to ship-type. Tables XX and XXI list the total number of transits and the number of collisions for the Table XIX column titled, "Passenger and Dry Cargo." Figure 4 shows the results of correlating collisions on a per transit basis versus ship length for passenger and cargo vessels. Also shown on Figure 4 is the exponential fit (Table XXII) for passenger and cargo vessels and for all vessels. Evaluation of Figure 4 indicates that the exponential fit is a good approximation for the trend shown and that the passenger and cargo vessels' trend is similar to that for all vessels up to ship lengths of 600 feet or greater. Above 600 feet, the

TABLE XIX.

RELATIONSHIP OF COAST GUARD AND WATERBORNE COMMERCE CATEGORIES OF SHIPS

Code	Vessel Type	Passenger and Dry Cargo	Tanker	Towboat or Tugboat	Non Self-Propelled Vessels
01	Artificial Island				X
02	Cargo Vessel (freight)	X			
03	Cargo Barges				X
04	Commercial Vessels	X			
05	Construction Vessels	X			
06	Dredges, self-propelled	X			
07	Dredges, non self-propelled				X
08	Fishing Vessels*	N/A	N/A	N/A	N/A
09	Tugs and Towboats			X	
10	Passenger Vessels	X			
11	Passenger Vessels	X			
12	Passenger Vessels	X			
13	Ferries	X			
14	Ferries	X			
15	Ferries	X			
16	Passenger Barges				X
17	Tankships		X		
18	Tank Barges				X
19	Public Passenger	X			
20	Public Cargo	X			
21	Public Tanker		X		
22	Public Vessels (Other)	X			
23	All Other U.S. Vessels	X			
24	Foreign Passenger	X			
25	Foreign Freight	X			
26	Foreign Tanker		X		
27	Foreign Vessels (Other)	X			
28	Cargo Barges				X
29	Tank Barges				X

*Transits for fishing vessels are not included in the Waterborne Commerce reports

TABLE XX.

TRANSITS FOR CALENDAR YEAR 1975 (2-WAY) - PASSENGER/CARGO

	Transits for Ship Length Intervals				
Region	< 400 Feet	400 < 500 Feet	500 < 600 Feet	600 < 700 Feet	≥ 700 Feet
Southern California	24,756	2,596	1,662	358	32
San Francisco	4,166	2,044	1,334	276	14
Puget Sound	121,684	1,458	562	176	58
Hawaii	7,838	400	670	202	32(1)
Alaska	20,624	406	298	0	2(2)
12 Month Total	179,068	6,904	4,526	1,012	138
15 Month Total	223,835	8,630	5,658	1,265	173

(1) Based on shifted exponential distribution (see Appendix D).

(2) Transits adjusted from 600 < 700 feet category to match transits with recorded collision length.

TABLE XXI.

COLLISIONS FOR PACIFIC WATERS (FY'76) - PASSENGER/CARGO

	Collisions for Ship Length Intervals				
Region	< 400 Feet	400 < 500 Feet	500 < 600 Feet	600 < 700 Feet	≥ 700 Feet
Southern California	9	2	1	2	1
San Francisco	6	0	1	2	1
Puget Sound	9	4	5	1	2
Hawaii	4	0	0	2	2
Alaska	8	2	1	0	1
Total	36	8	8	7	7

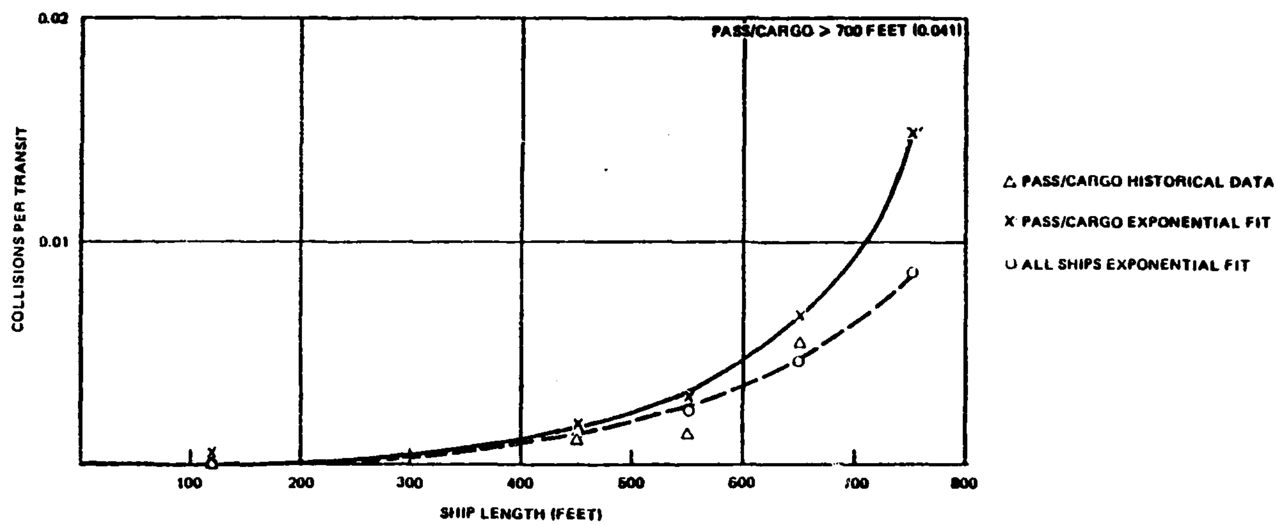


Figure 4. Collisions Per Transit Versus Ship Size for Passenger/Cargo Ships

TABLE XXII.

EXPONENTIAL FIT FOR PASSENGER/CARGO VESSELS

Shiplength, X (Midpoint Feet)	Collisions Per Transit Y	Log Y	X Log Y
120	0.000160833	- 3.793625495	- 455.2
450	0.000926999	- 3.032920809	-1364.8
550	0.001413927	- 2.849572956	-1567.3
650	0.005533597	- 2.256992485	-1467.0
750	0.040462428	- 1.392948063	-1044.7
2520	Not Used	-13.32605981	-5899.0

$$\text{Log } a = \frac{(\Sigma \log Y)\ (\Sigma X^2) - (\Sigma X)\ (\Sigma X \log Y)}{N\ \Sigma\ X^2 - (\Sigma X)^2}$$

$$= \frac{(-13.32605981)\ (1.5044 \times 10^6) - (2520)\ (-5899.0)}{(5)\ (1.5044 \times 10^6) - (6.3504 \times 10^6)}$$

$$= -4.423219$$

$$\text{Log } b = \frac{N\Sigma X \log Y - (\Sigma X)\ (\Sigma \log Y)}{N\Sigma X^2 - (\Sigma X)^2}$$

$$= \frac{(5)\ (-5899.0) - (2520)\ (-13.32605981)}{(5)\ (1.5044 \times 10^6) - (6.3504 \times 10^6)}$$

$$= 0.003488111$$

$$\text{Log } Y_{SF_{PASS/CARGO}} = \text{Log } a + X \text{ Log } b$$

$$= -4.423219 + (X)\ (0.00348811)$$

$$Y_{SF_{PASS/CARGO}} = (0.0000377)\ (1.008)^X$$

passenger and cargo trend diverges from that for all ships. This suggests that a multiplicative factor (π) for ship-type could be appropriate for very large ships (over 600 feet).

To determine if a ship-type multiplicative factor could be substantiated, a statistical test based upon the difference in proportions is used. The test is applied to ship length intervals of 500 <600 feet, 600 <700 feet, and equal to or greater than 700 feet. Table XXIII shows the values used in the statistical comparison test. The inputs for the comparison are based on Tables XX, XXI, XXIV and XXV. Since all traffic for ship lengths greater than 500 feet is associated with either tankers or passenger/cargo ships, the comparison is made between these two groups of vessels.

The parameter X/σ is used to determine significance at the 95 percent confidence level where

$$\frac{X}{\sigma} = \frac{P_1 - P_2}{\sigma_{\overline{X}_1 - \overline{X}_2}} \text{ and } \sigma_{\overline{X}_1 - \overline{X}_2} = \sqrt{\sigma_{P_1}{}^2 + \sigma_{P_2}{}^2}$$

$$\sigma_P = \sqrt{\frac{P(1-P)}{N}}$$

Table XXIII shows significance between tankers and passenger/cargo collisions for ship lengths $\geq$700 feet, and therefore a ship-type multiplicative factor is used. Comparison of the historical passenger/cargo collisions on an individual transit basis with the exponential trend for all ships suggests a multiplicative factor of 4.65 be applied (Figure 4). Similarly, a multiplicative factor of 0.20 is established for tankers. Thus, a second parameter of ship-type is

TABLE XXIII. SHIP-TYPE STATISTICAL COMPARISON
(1976 Data Base)

Parameter	Ship Length Intervals					
	500 < 600 feet		600 < 700 feet		≥700 feet	
Ship-type	Passenger Cargo	Tanker	Passenger Cargo	Tanker	Passenger Cargo	Tanker
Transits	5658	2110	1265	770	173	555
Collisions	8	3	7	5	7	1
Prob. of Collision (P)	0.001414	0.00142	0.00553	0.00649	0.0405	0.00180
σ_P	0.000499	0.000819	0.00209	0.002894	0.01499	0.001799
(1-P)	0.99858	0.99858	0.99447	0.99351	0.9595	0.9982
$\sigma_{\overline{X}_1 - \overline{X}_2}$	0.000959		0.00357		0.0151	
$\frac{X}{\sigma}$	0.01 (not significant)		0.27 (not significant)		2.56 (significant)	

TABLE XXIV.

TRANSITS FOR CALENDAR YEAR 1975 (2-WAY) - TANKERS

Region	Transits for Ship Length Intervals				
	< 400 feet	400 < 500 feet	500 < 600 feet	600 < 700 feet	≥ 700 feet
Southern California	766	404	762	402	378
San Francisco	408	346	480	76	12
Puget Sound	242	158	176	108	54
Hawaii	84	70	124	14	0
Alaska	262	120	146	16	0
12 Month Total	1,762	1,098	1,688	616	444
15 Month Total	2,203	1,373	2,110	770	555

TABLE XXV.

COLLISIONS FOR PACIFIC WATERS (FY'76) - TANKERS

Region	Collisions for Ship Length Intervals				
	< 400 feet	400 < 500 feet	500 < 600 feet	600 < 700 feet	≥ 700 feet
Southern California	0	0	1	2	1
San Francisco	0	0	2	2	0
Puget Sound	0	0	0	0	0
Hawaii	0	0	0	1	0
A aska	0	0	0	0	0
Total	0	0	3	5	1

identified and numerical values are assigned. This is reflected in the mathematical model as:

$$\text{Number of collisions} = \sum_{i=1}^{5} \sum_{j=1}^{3} \lambda_i \pi_{ij} T_{ij} \qquad (10)$$

where λ_i = collision rate as a function of ship length intervals.

$i = 1$ is $0 < 400$ feet.

$i = 2$ is $400 < 500$ feet.

$i = 3$ is $500 < 600$ feet.

$i = 4$ is $600 < 700$ feet.

$i = 5$ is ≥ 700 feet.

where π_{ij} = multiplicative factor for ship type.

$j = 1$ is passenger/cargo.

$j = 2$ is tanker.

$j = 3$ is other.

The ship-type multiplicative factors are given in Table XXVI.

TABLE XXVI. SHIP-TYPE MULTIPLICATIVE FACTORS (π_{ij})

Length Category (feet)	Ship-Type	Passenger/ Cargo	Tanker	Other
	i \ j	1	2	3
0 < 400	1	1.0	1.0	1.0
400 < 500	2	1.0	1.0	1.0
500 < 600	3	1.0	1.0	1.0
600 < 700	4	1.0	1.0	1.0
≥ 700	5	4.65	0.20	1.0

Ship Factor Summary

The ship factor contribution to predicting collisions can be represented mathematically by an exponential equation as a function of ship length. Multiplicative factors are used to adjust the trend to account for other ship factors other than ship length (size). One specific multiplicative factor is assigned to account for ship-type. In lieu of detailed data for multiplicative factors, other than ship-type, values of 1.0 are assumed.

Thus, the ship factor contribution is shown as:

$$Y_{SF} = \underbrace{(0.000066178)\ (1.006524879)^{X}}_{\lambda_i}\ (\pi_{ij}) = \lambda_{ij} \qquad (11)$$

where

λ_{ij} = collision rate for length category i and ship-type j.

λ_i = collision rate for length category i.

π_{ij} = multiplicative factor to account for the contribution of ship-type j in relation to ship length category i.

X = ship length midpoints for length category i.

Port Factors

A methodology similar to that utilized for ship factors is used to derive the mathematical relationships for port factors. As stated above, port associated parameters expected to contribute to collisions include the amount of traffic, port physical characteristics, weather, visibility, navigational aids, and port equipment.

Port Traffic

The approach used in evaluating the impact of port traffic on collisions is to determine whether or not a relationship exists between the number of collisions and the amount of traffic handled. Intuitively, it is felt that collisions would increase as the amount of traffic increased. In order to evaluate this concept, the number of collisions as a function of traffic were plotted (Figure 5) and a linear least squares fit was conducted. From Figure 5, it can be seen that, as a rule, the number of collisions does increase as transits increase. The other significant factor is that a correlation factor of 0.7 was obtained, thus indicating that a linear fit is appropriate for the data (References 5 and 6).

To convert this trend into equations for the Collision Prediction Model, the following approach was used on the 1976 data:

1) A linear least squares fit was used to define a relationship between number of collisions and transits. This least squares fit is hypothesized to represent the expected number of collisions for hypothetical ports as a function of transits.
2) Since the least squares fit represents the expected number of collisions, points lying on the least squares line are assigned a multiplicative factor of 1.0.
3) Since ports can be expected to vary significantly from the hypothetical port, a multiplier is assigned for each port based on a comparison of the historical number of collisions and the least squares expected number of collisions. This multiplier is calculated by dividing the number of

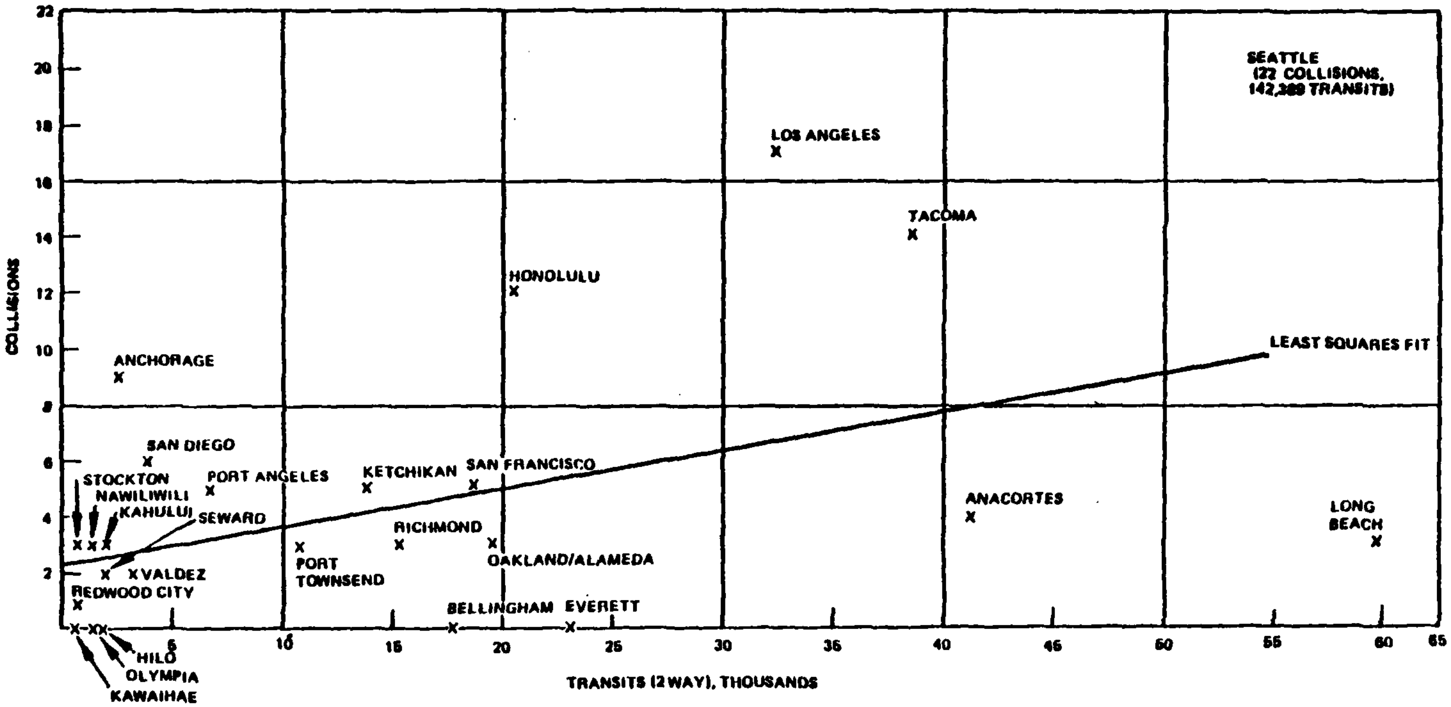


Figure 5. Collisions as a Function of Traffic for Pacific Coast Ports for 1976

collisions experienced in 1976 by the expected number of collisions based upon the least squares fit of 1976 transit data. This multiplier is designated π_{pt}.

4) The multiplier π_{pt} is incorporated directly in the Collision Prediction Model as a multiplicative factor.

For example, from Figure 5, Tacoma is shown as having approximately 86 percent $\left(\frac{14}{7.5}\right)$ more collisions than would be expected for a port with approximately 40,000 transits. Therefore, a π_{pt} multiplier of 1.86 is assigned. Similar evaluations for other ports are presented in Table XXVII. For ports with no observed collisions during the data evaluation period, π_{pt} should be a small number. An arbitrary π_{pt} value of 0.10 is assigned in order to match predicted and observed collisions.

Initial predictions or estimates of 1976 collisions using the CPM are now made possible with the inclusion of a port factor multiplier. These initial predictions are given in Table XXVIII. A comparison with 1976 historical results is made to see how the CPM estimates match historical results. The CPM may be adjusted or expanded to predict collisions more accurately based on the comparison of predictions and historical results. This may take the form of additional multipliers, changes in multiplier values, or incorporation of new mathematical relationships. Figure 6 illustrates this adaptive process.

Evaluation of Table XXVIII results in the conclusion that some of the collision estimates do not meet the criteria established for deriving the Collision Prediction Model equations and coefficients.

TABLE XXVII. TABULATION OF π_{pt}
(Based on 1976 Data)

Port	Expected Port Collisions	Observed Collisions	π_{pt}
San Diego	2.99	6	2.0
Long Beach	10.20	3	0.29
Los Angeles	6.70	17	2.54
San Francisco	4.94	5	1.01
Redwood City	2.57	1	0.39
Oakland/Alameda	5.02	3	0.60
Stockton	2.61	3	1.15
Port Angeles	3.36	5	1.49
Port Townsend	4.22	3	0.71
Seattle	20.99	22	1.05
Tacoma	7.51	14	1.86
Olympia	2.70	0	0.10
Everett	5.48	0	0.10
Anacortes	7.83	4	0.51
Hilo	2.70	0	0.10
Kawaihae	2.58	0	0.10
Kahului	2.76	3	1.09
Nawiliwili	2.64	3	1.13
Honolulu	5.16	12	2.33
Valdez	2.88	2	0.69
Anchorage	2.81	9	3.20

Expected Port Collisions = 2.48 + 0.00013 X (Number of Transits)

π_{pt} = Observed Collisions ÷ Expected Port Collisions

TABLE XXVIII. COLLISIONS EXPECTED WITH PORT MULTIPLICATIVE FACTOR, π_{pt}

Ship Length (Feet)

Port	Total Traffic (15 months)	π_{pt}	0 <400		400 <500		500 <600		600 <700		≥700		Predicted	Observed
			Transits	Collisions	Transits	Collisions	Transits	Collisions	Transits	Collisions	Transits	Collisions		
Redwood City	698	0.39	685	0.04	8	0.00	5	0.00	0	0.00	0	0.00	0.04	1
Kawaihae	748	0.10	723	0.01	15	0.00	5	0.00	5	0.00	0	0.00	0.01	0
Stockton	984	1.15	833	0.14	100	0.14	48	0.13	3	0.02	0	0.00	0.43	3
Nawiliwili	1,267	1.13	1,238	0.19	8	0.02	18	0.05	5	0.02	0	0.00	0.28	3
Hilo	1,659	0.10	1,475	0.02	123	0.02	38	0.01	23	0.01	0	0.00	0.06	0
Olympia	1,713	0.10	1,688	0.02	20	0.00	5	0.00	0	0.00	0	0.00	0.02	0
Kahului	2,149	1.09	1,963	0.31	143	0.19	30	0.08	13	0.07	0	0.00	0.65	3
Anchorage	2,544	3.20	1,888	0.87	253	1.00	380	2.92	21	0.30	2	0.25	5.3	9
Valdez	3,063	0.69	2,935	0.30	85	0.07	43	0.07	0	0.00	0	0.00	0.44	2
San Diego	3,949	2.0	3,602	1.04	178	0.44	113	0.54	48	0.43	8	0.48	2.93	6
Port Angeles	6,604	1.49	6,468	1.39	60	0.11	40	0.14	18	0.12	18	1.03	2.84	5
Port Townsend	13,399	0.71	13,383	1.37	13	0.01	3	0.01	0	0.00	0	0.00	1.39	3
San Francisco	18,909	1.01	17,520	2.55	813	1.01	498	1.19	68	0.31	10	0.41	5.47	5
Oakland/Alameda	19,524	0.60	16,545	1.44	1,585	1.17	1,108	1.53	278	0.75	8	0.19	5.08	3
Honolulu	20,593	2.33	18,905	6.33	520	1.49	903	4.84	265	2.77	0	0.00	15.43	12
Everett	23,099	0.10	22,900	0.33	128	0.02	30	0.01	18	0.01	23	0.03	0.46	0
Los Angeles	32,469	2.54	28,330	10.36	1,988	6.21	1,463	8.55	473	5.41	215	2.23	32.76	17
Tacoma	38,721	1.86	37,893	10.15	510	1.17	195	0.83	88	0.74	35	2.26	15.15	14
Anacortes	41,123	0.51	40,895	3.00	78	0.05	50	0.06	40	0.10	60	0.05	3.27	4
Long Beach	59,433	0.29	55,643	2.32	1,615	0.57	1,455	0.98	430	0.56	290	0.40	4.83	3
Seattle	142,389	1.05	140,220	21.20	1,408	1.82	575	1.43	183	0.87	3	0.01	25.33	22

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A METHODOLOGY FOR ASSESSING ALTERNATIVES TO REDUCE SHIP COLLISI--ETC(U)
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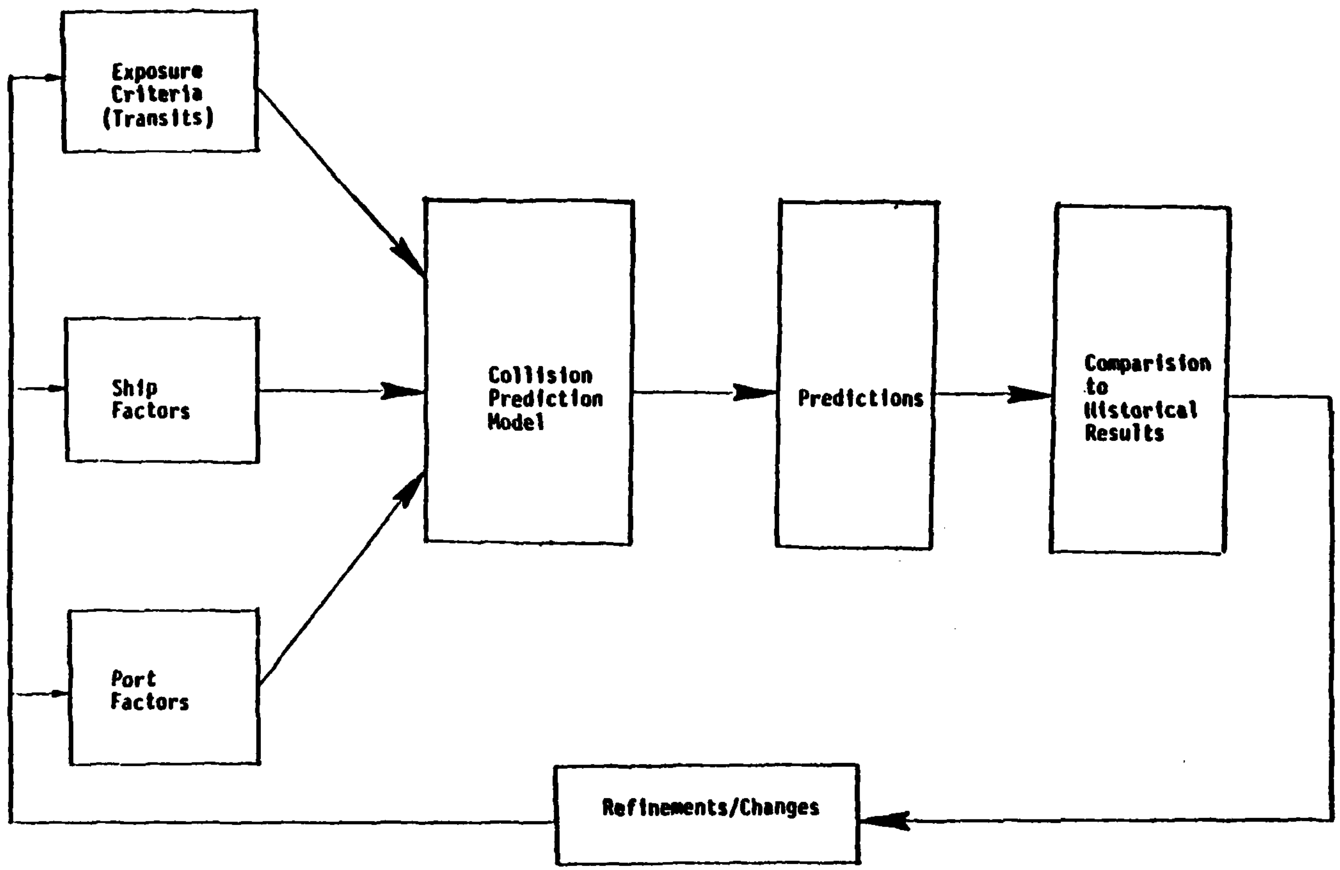

Figure 6. Adaptive Process of the Collision Prediction Model

Therefore, another factor is considered to match historical results more closely.

Traffic - Berthing Space

The previous subsection proposed a method to account for individual differences among ports by comparing historical collisions with expected collisions. Table XXVIII tabulated initial estimates of 1976 collisions using the CPM which incorporated a single port multiplier, π_{pt}. A comparison of the predictions with historical results shows that another port factor need be determined which assists in predicting collisions more accurately. This new factor deals with the magnitude of activity for a port and is based on the traffic a port handles and the amount of berthing space. The use of a second port factor multiplier is necessary since the CPM's collision rates (λ_{ij}) of collisions per transit are heavily influenced by ports with large amounts of traffic. For example, Seattle transits represent approximately 17% of all transits used in this research. Therefore, the collisions per transit (λ_{ij}) are heavily influenced by the Seattle data. This can be seen by examination of Table XXVIII, where the expected number of collisions, 22.89 for Seattle, is very close to the observed collisions (22). The use of a π_{pm} multiplier compensates for the fact that collision rates are heavily affected by ports with large amounts of traffic.

In order to evaluate this concept, port characteristics were obtained from the Port Series publications published by the U. S. Army Corps of Engineers. Information contained in Port Series applicable to this research includes the number of piers, wharfs

and docks, and berthing space. These publications, which include berthing space information, are available for the following Pacific Ocean ports: San Diego, Long Beach, Los Angeles (including San Pedro and Wilmington), San Francisco, Redwood City, Oakland, Alameda, Stockton, Port Angeles, Port Townsend, Seattle, Tacoma, Olympia, Everett, Anacortes, Hilo, Kawaihae, Kahului, Nawiliwili, Honolulu, Anchorage, Seward and Valdez.

Table XXIX tabulates port characteristics. The column entitled "Average Daily Traffic X Berthing Space" is significant in identifying the magnitude of activity associated with individual ports. For example, a port such as Seattle, which handles a vast amount of traffic (142,389 transits) and has significant berthing space (40,213 feet) can be classified in a different magnitude of activity category than Hilo, Hawaii, with 1,659 transits and 3,023 feet of berthing space. To account for these variations, five categories of port magnitude of activity are assigned. Table XXIX separates the ports into the five categories: ultra large, very large, large, medium and small. The criteria for distinguishing ports into these categories are based on the parameter "Average Traffic per day X Berthing Space," with ultra large including values $\geq 1.25 \times 10^7$, very large $\geq 2 \times 10^6$, large $\geq 2.5 \times 10^5$, medium $\geq 1.75 \times 10^4$ and small $< 1.75 \times 10^4$.

A multiplicative factor, π_{pm}, is incorporated in the Collision Prediction Model to account for these variations. The values of π_{pm} are calculated by comparing predicted collisions without the π_{pm} multiplicative factor, to historical results, and then determining

TABLE XXIX. PORT CHARACTERISTICS

Location	Berthing Space (Feet)	Piers Wharfs Docks	1976 Traffic (15 Months)	Collisions (Without Fishing Or Naval Vessels)	Average Traffic Per Day X Berthing Space	Magnitude of Activity	π_{pm}
Seattle	40,213	207	142,389	22	1.27×10^7	Ultra Large	1.0
Long Beach	21,074	68	59,433	3	2.78×10^6	Very Large	0.57
Los Angeles	35,972	128	32,468	17	2.6×10^6	Very Large	0.57
Tacoma	11,760	99	38,721	14	1.01×10^6	Large	0.85
Anacortes	10,762	26	41,123	4	9.8×10^5	Large	0.85
Everett	15,492	42	23,099	0	7.95×10^5	Large	0.85
Horolulu	14,641	66	20,593	12	6.7×10^5	Large	0.85
San Francisco	29,444	68	18,909	5	1.23×10^6	Large	0.85
Oakland/ Alameda	21,107	60	19,524	3	9.15×10^5	Large	0.85
Port Townsend	2,475	13	13,399	3	7.4×10^4	Medium	1.9
Port Angeles	11,479	30	6,604	5	1.7×10^5	Medium	1.9
San Diego	12,541	95	3,949	6	1.1×10^5	Medium	1.9
Valdez	6,715	11	3,063	2	4.6×10^4	Medium	1.9
Anchorage	4,464	9	2,544	9	2.5×10^4	Medium	1.9

TABLE XXIX. PORT CHARACTERISTICS (Continued)

Location	Berthing Space (Feet)	Piers Wharfs Docks	1976 Traffic (15 Months)	Collisions (Without Fishing Or Naval Vessels)	Average Traffic Per Day X Berthing Space	Magnitude of Activity	π_{pm}
Kahului	1,969	2	2,149	3	9.4×10^3	Small	5.0
Hilo	3,023	4	1,659	0	1.1×10^4	Small	5.0
Nawiliwili	1,140	1	1,267	3	3.2×10^3	Small	5.0
Olympia	3,295	8	1,713	0	1.25×10^4	Small	5.0
Stockton	4,931	27	984	3	1.08×10^4	Small	5.0
Kawaihae	1,015	2	748	0	1.7×10^3	Small	5.0
Redwood City	4,670	9	698	1	7.2×10^3	Small	5.0
Seward	3,337	7	2,016	2	1.5×10^4	Small	5.0

an appropriate π_{pm} multiplier to result in the final model predicted collisions being close to historical results.

Table XXIX lists the values of π_{pm} assigned to individual ports based upon the port's activity level.

Methodology for Incorporating Other Port Factors

In addition to assigning π_{pt} and π_{pm} multipliers based on port physical characteristics (berthing space), usage (transits) and historical results (number of collisions reported), the mathematical model must be capable of accommodating the definition of additional port parameters or incorporating the predicted effect for changes in port characteristics. The approach taken is similar to that used for ship factors. As an approximation, this capability is incorporated in the form of multiplicative factors as shown in:

$$Y_{PF} = (\pi_{pt})\ (\pi_{pm})\ (\pi_{OTHER}) = (\pi_p) \qquad (12)$$

where Y_{PF} = port multiplicative factor.

π_{pt} = multiplicative factor based on port traffic, expected collisions and historical results (Table XXVIII).

π_{pm} = multiplicative factor for port p based upon magnitude of activity (Table XXIX).

π_p = multiplicative factor for port contribution. For $\pi_{OTHER} = 1$, $\pi_p = \pi_{pt}\ \pi_{pm}$.

π_{OTHER} = undefined multiplicative factors for other port factors to allow for the introduction of changes in port characteristics. A value of 1.0 is used until the specific parameter is defined.

The capability to define new multipliers (π_{OTHER}) provides a means to incorporate in the CPM the effect of changes in port characteristics on collisions. For example, the introduction of a Vessel Traffic System could be expected to reduce collisions by 10 percent, and therefore a $\pi_{\substack{\text{Port} \\ \text{Equipment}}}$ could be defined and assigned a value of 0.9.

Collision Prediction Model (CPM)

Equation 12 represents the port factor contribution to collision prediction. The port factor contribution is not expected to vary among the five ship length categories. Therefore,

$$Y_{PF} = (\pi_{pt})\ (\pi_{pm})\ (\pi_{OTHER}) = (\pi_p).$$

Assuming $\pi_{OTHER} = 1.0$, $Y_{PF} = (\pi_{pt})\ (\pi_{pm}) = (\pi_p)$.

The generalized Collision Prediction Model is arrived at by combining the port factor equation with the ship factor equation and exposure criteria (transits).

$$\text{Number of collisions} = \sum_{i=1}^{5} \sum_{j=1}^{3} \sum_{p=1}^{21} \lambda_{ijp} T_{ijp} = \lambda_i \pi_{ij} \pi_p T_{ijp} \quad (13)$$

where

λ_{ijp} = collision per transit for length category i, ship-type j and port p.

T_{ijp} = transits for length category i, ship-type j and port p.

λ_i = collision rate for length category i.

π_{ij} = multiplicative factor to account for the contribution of ship-type j in relation to ship length category i.

π_p = multiplicative factor for port contribution. For

$\pi_{OTHER} = 1$, $\pi_p = \pi_{pt}\,\pi_{pm}$.

If we include the numerically derived ship factor equation (11), the CPM can be written as:

Number of collisions =

$$\sum_{i=1}^{5}\sum_{j=1}^{3}\sum_{p=1}^{21} (0.000066178)(1.006524879)^{X}(\pi_{ij})(\pi_p)(T_{ijp}) \qquad (14)$$

where

X = ship length midpoints for length category i.

π_{ij} = multiplicative factor to account for the contribution of ship-type j in relation to ship length category i (from Table XXVI).

π_p = multiplicative factor for port contribution (from Tables XXVII and XXIX).

T_{ijp} = transits for length category i, ship-type j and port p.

Table XXX shows the results of using the Collision Prediction Model to predict collisions for the 15-month, FY 1976, time period. Excellent agreement is seen between predictions and observed collisions from both a relative ranking viewpoint and actual number of collisions. Validation of the model is described in the next section.

TABLE XXX. 1976 PREDICTED COLLISIONS
(COLLISION PREDICTION MODEL)

Port	Observed Collisions	Predicted Collisions	To Nearest Collision
Seattle	22	25.33	25
Los Angeles	17	18.67	19
Tacoma	14	12.88	13
Honolulu	12	13.12	13
Anchorage	9	10.03	10
San Diego	6	5.57	6
Port Angeles	5	5.40	5
San Francisco	5	4.65	5
Anacortes	4	2.78	3
Stockton	3	2.15	2
Oakland	3	4.32	4
Port Townsend	3	2.64	3
Long Beach	3	2.75	3
Kahului	3	3.25	3
Nawiliwili	3	1.40	1
Valdez	2	0.84	1
Redwood City	1	0.20	0
Olympia	0	0.10	0
Everett	0	0.39	0
Hilo	0	0.30	0
Kawaihae	0	0.05	0
Total	115	116.82	116

VII. VALIDATION OF THE COLLISION PREDICTION MODEL

The Collision Prediction Model (CPM), which was generated based on 1976 historical data, is validated by several means. First, the methodology used in deriving the Collision Prediction Model is validated by comparing the CPM's results for 1976 with 1976 historical results in order to see how well the model matches the data base upon which it was derived (see Figure 7). Second, the methodology of using ship factors, transits and port factors is confirmed by applying the same methodology to two additional data bases. The first new data base consists of FY 1977 vessel casualty data (Appendix E) and appropriate transit data. The second data base consists of the combined 1976 and 1977 data bases. Next, the CPM's ability to forecast collisions is tested by forecasting 1977 collisions without a priori knowledge of 1977 collision statistics. During these evaluations, absolute and relative ranking comparisons are conducted in order to analyze the Collision Prediction Model's ability to predict absolute values of collisions and to predict relative ranking of ports based on number of collisions. Finally, a recursive weighted least squares solution is introduced to incorporate the adaptive feature of the model to predict collisions more accurately over a long period of time. Results from 1976 and 1977 are incorporated to generate an iteration of the Collision Prediction Model.

As stated in Section VI, the development of the Collision Prediction Model is based on either of the following criteria:

1) predicted collisions should be within 2 of historical results, or

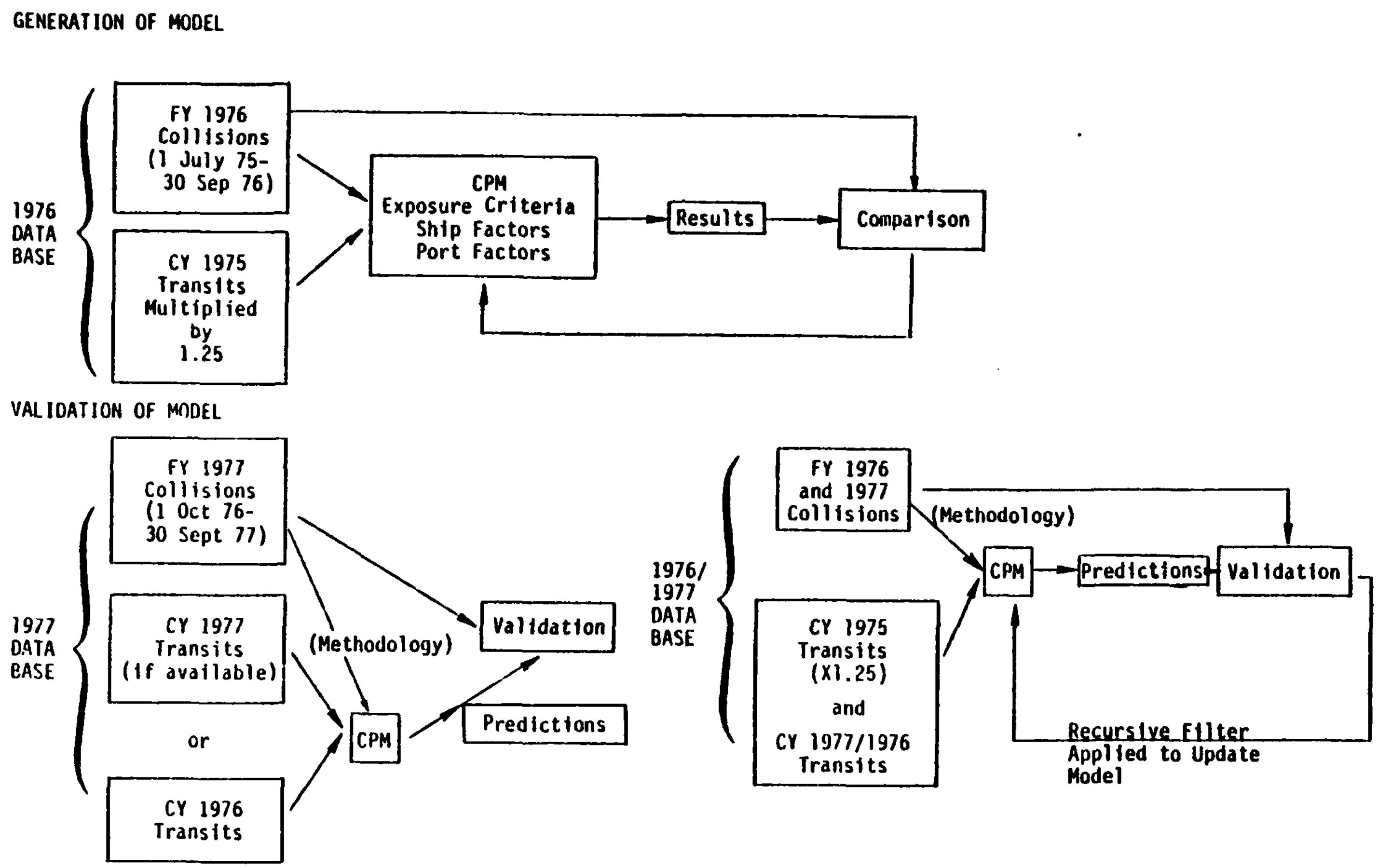

Figure 7 Generation and Validation of the Collision Prediction Model

2) predicted collisions should be within 25 percent of historical results for ports with more than eight collisions during the evaluation period. These criteria were selected based upon objective judgment of the CPM's accuracy required to match the data upon which it is derived. The accuracy required of the CPM to forecast collisions without a priori knowledge of collision statistics is evaluated by analyzing the accuracy required of the CPM to allow effective use in analyzing alternatives to ship collisions.

Evaluation of the CPM Based on 1976 Results

Evaluation of 1976 results is important to determine whether or not the model accurately estimates collisions for the data base used in generating the model. Two observations are made. The first deals with comparing the absolute values of predicted collisions with those recorded. The second comparison is based on the ability of the CPM to predict relative ranking of ports based on number of collisions.

Absolute Value Comparison

A review of Table XXX allows evaluation of the ability of the CPM to predict the number of collisions for the ports analyzed. In every case, predicted collisions are within 2 collisions or 25 percent of historical collisions. In addition, 115 collisions were observed in the ports listed. The Collision Prediction Model predicts a total of 116.82 collisions, for very close agreement on an absolute comparison basis.

Relative Ranking Comparison

The ability of the CPM to predict the ranking of ports as a function of collisions can be as important as predicting the

approximate number of collisions. Information from relative ranking can be used to identify priorities in considering what collision reduction alternatives should be considered and where. Therefore, a ranking test is applied to see how accurate the CPM is in predicting relative ranking. The ranking test is accomplished by listing the ports in descending (or ascending) order based upon historical results. If the Collision Prediction Model predicted collisions in exactly the reverse order (port with most collisions last and port with least collisions first), that would be the worst possible case. A mathematical figure of goodness is achieved by comparing the CPM results with the worst possible case. A figure of 1.0 says that the CPM produced the worst possible results while a figure of 0.0 says that the CPM matched the historical results exactly. Table XXXI shows the results of the relative ranking test. Ports with the same number of collisions are weighted equally. CPM results rounded off to the nearest collision are used for the test. A relative ranking indication of 0.01 is considered excellent (see Appendix F).

Summary of 1976 Results

Excellent correlation is seen between 1976 historical results and CPM predictions. In every case, the criteria selected for developing the model were met and in many cases exceeded. Therefore, the model should be useful for approximating collisions, relative ranking of ports, and determining the numerical difference in expected collisions from year-to-year.

Model Generation Methodology Applied to Additional Data Bases

To show the validity of the methodology used to generate the CPM,

TABLE XXXI. RELATIVE RANKING COMPARISON

	Historical Ranking (Most to Least)	CPM Ranking (Most to Least)	Δ'	$(\Delta')^2$	Δ Maximum Inverse	Δ^2 Maximum Inverse
Seattle	1	1	0	0	20	400
Los Angeles	2	2	0	0	18	324
Tacoma	3	3.5	0.5	0.25	16	256
Honolulu	4	3.5	0.5	0.25	14	196
Anchorage	5	5	0	0	12	144
San Diego	6	6	0	0	10	100
Port Angeles	7.5	7.5	0	0	8	64
San Francisco	7.5	7.5	0	0	6	36
Anacortes	9	11.5	2.5	6.25	4	16
Oakland	12.5	9	3.5	12.25	2	4
Stockton	12.5	14	1.5	2.25	0	0
Port Townsend	12.5	11.5	1.0	1.0	2	4
Long Beach	12.5	11.5	1.0	1.0	4	16
Kahului	12.5	11.5	1.0	1.0	6	36
Nawiliwili	12.5	15.5	3.0	9.0	8	64
Valdez	16	15.5	0.5	0.25	10	100
Redwood City	17	19	2	4	12	144
Olympia	19.5	19	0.5	0.25	14	196
Everett	19.5	19	0.5	0.25	16	256
Hilo	19.5	19	0.5	0.25	18	324
Kawaihae	19.5	19	0.5	0.25	20	400
			$\sum 38.50$		$\sum 3080$	

Relative Ranking Indicator $= \dfrac{\Sigma(\Delta')^2}{\Sigma\Delta^2} = \dfrac{38.5}{3080} = 0.01$

two new data bases are considered. The first deals with Fiscal Year 1977 vessel casualties and the second applies the methodology to the combined Fiscal Year 1976 and 1977 vessel casualties. Figure 7 illustrates the data used in generating the model and validating the Collision Prediction Model. As shown in this figure, the 1976 data base was used to generate the CPM and the 1977 and combined 1976/1977 data bases were used to validate the model.

To identify the collisions which applied to the 1977 traffic data, a similar analysis to that conducted for 1976 was accomplished. Appendix E describes the analysis used to arrive at the 1977 collision statistics.

Based on the analysis documented in Appendix E, the 1977 collision statistics are presented in Table XXXII. A similar analysis to that conducted for 1976 traffic of correlating draft versus length was conducted, and the results for 1977 are given in Table XXXIII. Traffic data for 1977 were used where available. The 1977 data were provided in preliminary form by the U. S. Army Corps of Engineers. Traffic data for 1976 were used for those ports for which 1977 data were not available. It is not expected that the differences between 1976 and 1977 traffic will have a significant effect on the CPM's results.

<u>Ship Factors</u>

The CPM incorporates an exponential equation to fit collisions per transit versus ship length. Figure 8 shows a comparison of the exponential fit with 1976, 1977 and combined 1976/1977 collision statistics. Excellent correlation of the exponential trend is

TABLE XXXII. 1977 COLLISION STATISTICS

	Ship Length (feet)					
Port	< 400	400 < 500	500 < 600	600 < 700	≥ 700	Total
Honolulu	4	0	0	0	0	4
Hilo	0	0	0	0	0	0
Kahului	1	0	0	0	0	1
Kawaihae	2	0	0	0	0	2
Nawiliwili	0	0	0	0	0	0
San Diego	11	0	0	0	1	12
Long Beach	5	0	3	0	0	8
Los Angeles	8	0	2	2	0	12
Anchorage	1	0	1	0	0	2
Valdez	0	0	0	0	0	0
Olympia	0	0	0	0	0	0
Everett	0	0	0	0	0	0
Seattle	16	4	2	1	1	24
Anacortes	0	0	0	0	0	0
Tacoma	6	1	0	2	0	9
Port Angeles	0	0	0	0	0	0
Port Townsend	0	0	0	0	0	0
San Francisco	12	1	1	1	1	16
Stockton	0	0	0	0	0	0
Oakland	0	0	0	0	0	0
Redwood City	0	0	0	0	0	0
Totals	66	6	9	6	3	90

TABLE XXXIII. 1977 DATA BASE TRAFFIC STATISTICS

Port	Ship Length (feet)					
	< 400	400 < 500	500 < 600	600 < 700	≥ 700	Total
Honolulu*	18,114	412	680	232	10	19,448
Hilo*	1,120	98	42	6	0	1,266
Kahului*	1,524	170	46	4	0	1,744
Kawaihae*	538	14	8	4	0	564
Nawiliwili*	1,534	16	10	0	0	1,560
San Diego	2,970	120	24	26	2	3,142
Long Beach	56,820	1,184	1,232	420	434	60,090
Los Angeles	37,998	1,568	1,336	436	188	41,526
Anchorage*	988	314	248	20	0	1,570
Valdez*	1,320	46	28	0	0	1,394
Olympia	1,532	8	8	2	0	1,550
Everett	20,470	92	50	6	10	20,628
Seattle	116,612	1,008	636	294	4	118,554
Anacortes	26,884	48	36	86	124	27,178
Tacoma	34,390	514	200	78	50	35,232
Port Angeles	6,916	58	28	18	4	7,024
Port Townsend	9,626	8	0	0	0	9,634
San Francisco	12,884	604	318	48	0+	13,854
Stockton	410	30	36	2	0	478
Oakland	7,456	1,068	1,122	336	2	9,984
Redwood City	338	8	4	0	0	350
Totals	360,444	7,388	6,092	2,018	828	376,770

*Based on CY 1976 transits. All other ports are based on CY 1977 transits.

+For evaluation of San Francisco, use the shifted exponential distribution of Appendix D to estimate transits for the ≥700 feet ship length category.

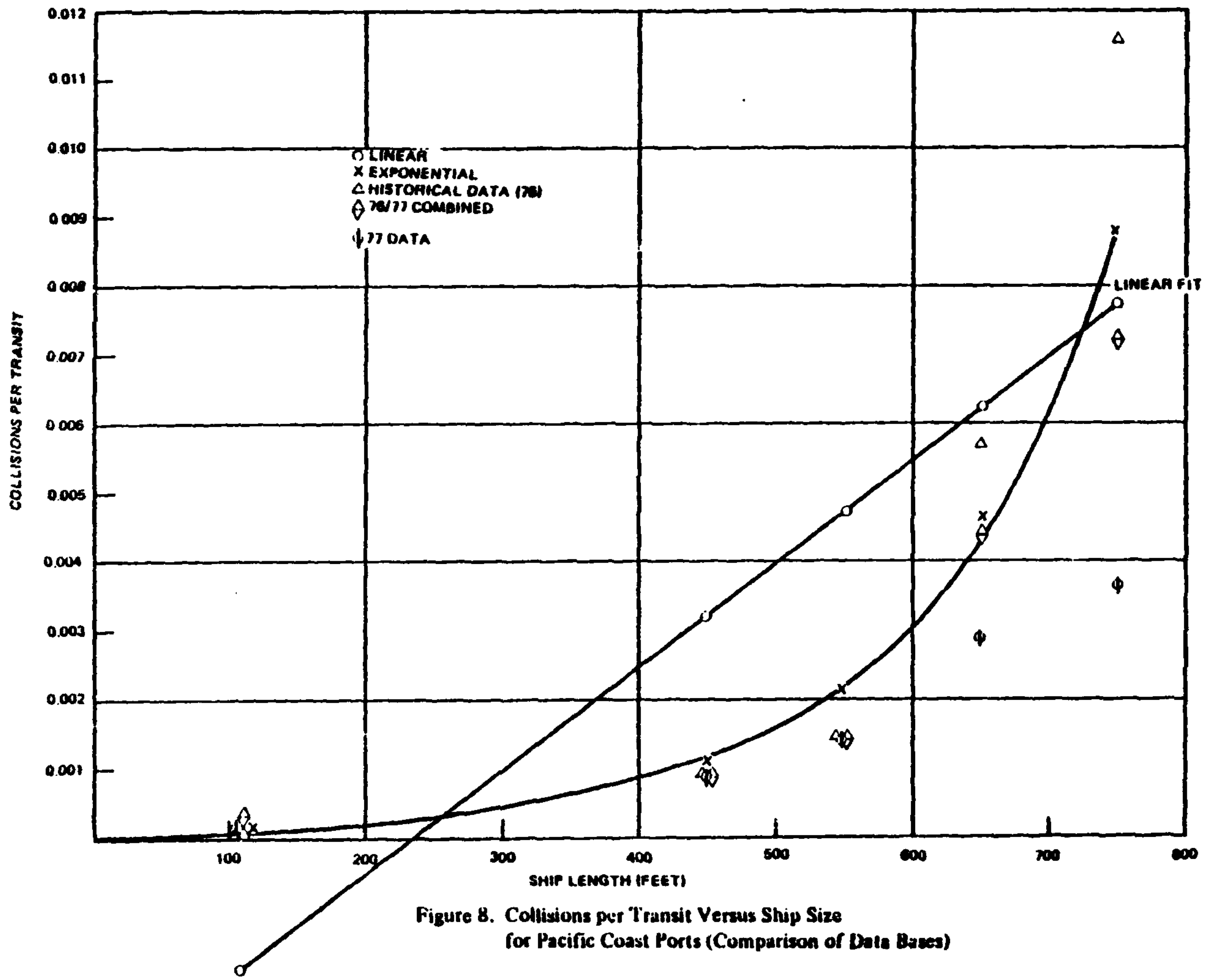

Figure 8. Collisions per Transit Versus Ship Size for Pacific Coast Ports (Comparison of Data Bases)

observed, thus validating the exponential fit of collisions per transit versus ship size.

The next validation deals with the ship-type multiplicative factor (π_{ij}). As discussed in Section VII, a ship-type multiplicative factor was substantiated based upon the 1976 data base. The ship-type factor was incorporated in the CPM to account for the difference in collision rates between tankers and passenger/cargo vessels for vessels over 700 feet in length. A similar statistical analysis to that performed for 1976 and reported in Table XXIII is conducted on the combined 1976/1977 data base. Table XXXIV summarizes the transits and collisions for large ships and shows the results of the statistical test. Similar to the analysis based upon the 1976 data base, the results of the analysis for the combined 1976/1977 data base show a significant difference between collision rates for tankers and passenger/cargo vessels greater than 700 feet in length. Therefore, the ship-type multiplicative factor is retained based on the above rationale.

Port Factors

The same approach used in developing the port factors is applied to both the 1977 and 1976/1977 data bases. First, the impact of port traffic on the number of collisions is evaluated by conducting a least squares fit of collisions and traffic using the 1976, 1977 and 1976/1977 data bases. Figure 9 shows this evaluation. As seen in Figure 9, excellent verification of a positive correlation between collisions and transits is obtained. Correlation factors of 0.7, 0.72, and 0.78 are obtained for the least squares fit of the 1976,

TABLE XXXIV. SHIP-TYPE STATISTICAL COMPARISON

(Combined 1976/1977 Data Base)

Item	Ship Length Intervals					
	500 < 600 feet		600 < 700 feet		$\geq$ 700 feet	
	Passenger Cargo	Tanker	Passenger Cargo	Tanker	Passenger Cargo	Tanker
Transits	10,670	3576	2663	1632	347	1229
Collisions	14	6	12	7	8	3
Prob. of Collision (P)	0.00131	0.00168	0.00451	0.00429	0.02305	0.00244
(1-P)	0.99869	0.99832	0.99549	0.99571	0.97695	0.99756
σ_p	0.00035	0.00068	0.00449	0.00162	0.00806	0.00141
$\sigma_{\bar{X}_1 - \bar{X}_2}$	0.00077		0.00477		0.00818	
$\frac{X}{\sigma}$	-0.48 (not significant)		0.05 (not significant)		2.52 (significant)	

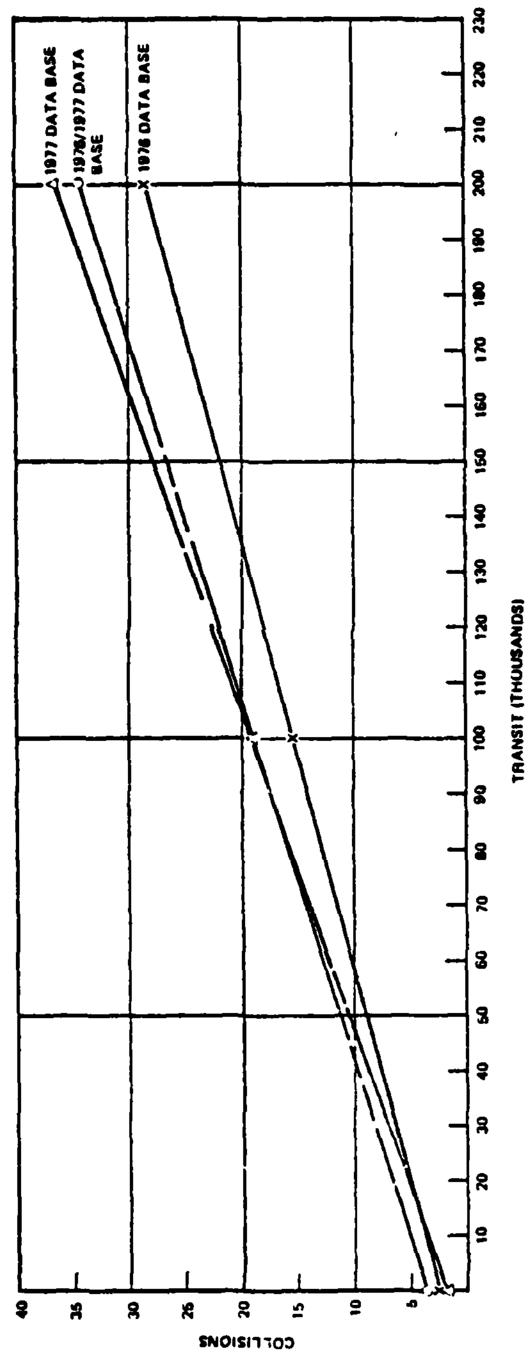

Figure 9. Collisions as a Function of Traffic for Pacific Coast Ports (Comparison of Data Bases)

1977, and 1976/1977 data bases, respectively. These correlation factors demonstrate the consistency of the data and validate that a linear least squares fit can be used to relate collisions and transits mathematically (References 5 and 6).

Methodology Applied to 1977 Data Base

To demonstrate its validity, the method used to generate the Collision Prediction Model (CPM) is applied to the 1977 data base. The three inputs required to "predict" collisions are transits, ship factors and port factors.

Transits

Traffic data for 1977 are used where available. These were provided in preliminary form by the U. S. Army Corps of Engineers. Traffic data for 1976 were used for those ports for which 1977 data were not available. Figure 7 illustrates the data that comprise the 1977 data base.

Ship Factors

Since the CPM ship factor exponential fit based on the 1976 data base closely matches the 1977 data, the CPM ship factor equations are used unchanged in evaluating the method as applied to the 1977 data base.

Port Factors

New π_{pt} multipliers are used to reflect the 1977 historical results. These π_{pt} multipliers are derived by comparing 1977 port collisions with the expected 1977 least squares fit given in Figure 9. Since the collisions and transits between 1976 and 1977

are similar, and since the ports have similar magnitudes of activity between 1976 and 1977, the original π_{pm} multipliers are used.

Results

The results of this analysis are shown in Table XXXV. As shown, use of the Collision Prediction Model results in all of the 1977 predicted collisions meeting the criteria chosen for generating the model. These results are considered sufficient to establish the ability of the CPM to match collision data. Further matching of the predicted and historical data could be achieved by using the π_{ij} and π_{pm} values derived from 1977 data. However, since the purpose is to validate the methodology and not the absolute values, and since all predictions meet the necessary criteria, adjustment of these values is considered unnecessary to validate the methodology.

Methodology Applied to Combined 1976/1977 Data Base

A similar analysis to that performed on the 1977 data base is conducted on the combined 1976/1977 data base. Again, the CPM ship factor equations based on 1976 data are used. New π_{pm} multipliers are derived, based on historical port collisions, with the least squares fit for 1976/1977 shown in Figure 9. The results of the analysis are given in Table XXXVI. Without exception, the predicted collisions meet the CPM criteria. Based on the above analysis, it is concluded that the methodology used to generate the CPM is accurate in matching the data used to generate the model.

CPM Predictions and 1977 Results

The previous sections demonstrate that a methodology has been

TABLE XXXV. CPM METHODOLOGY APPLIED TO 1977 DATA BASE

Port	Transits	Ship Factor Predictions	π_{pt}	π_{pm}	Predicted Collisions	Historical Collisions
Seattle	118,554	21.01	1.07	1.0	22.5	24
Long Beach	60,090	17.69	0.66	0.57	6.7	8
Los Angeles	41,526	14.37	1.36	0.57	11.1	12
Tacoma	35,232	7.64	1.16	0.85	7.6	9
Anacortes	27,178	4.71	0.1	0.85	0.4	0
Everett	20,628	3.55	0.1	0.85	0.3	0
Honolulu	19,448	6.17	0.81	0.85	4.2	4
San Francisco	13,854	3.56	4.05	0.85	12.3	16
Oakland	9,984	6.59	0.1	0.85	0.6	0
Port Townsend	9,634	1.41	0.1	1.9	0.3	0
Port Angeles	7,024	1.23	0.1	1.9	0.2	0
San Diego	3,142	0.83	5.84	1.9	9.2	12
Valdez	1,394	0.31	0.1	1.9	0.1	0
Anchorage	1,570	1.20	1.12	1.9	2.6	2
Kahului	1,744	0.54	0.55	5.0	1.5	1
Hilo	1,266	0.43	0.1	5.0	0.2	0
Olympia	1,550	0.25	0.1	5.0	0.1	0
Nawiliwili	1,560	0.23	0.1	5.0	0.1	0
Stockton	478	0.21	0.1	5.0	0.1	0
Kawaihae	564	0.14	1.25	5.0	0.9	2
Redwood City	350	0.07	0.1	5.0	0.0	0

TABLE XXXVI.
CPM METHODOLOGY APPLIED TO COMBINED 1976/1977 DATA BASE

Port	Transits	Ship Factor Predictions	π_{pt}	π_{pm}	Predicted Collisions	Historical Collisions
Seattle	260,942	45.11	1.05	1.0	47.4	46
Long Beach	119,523	34.35	0.50	0.57	9.8	11
Los Angeles	73,994	27.27	1.91	0.57	29.7	29
Tacoma	73,945	15.78	1.51	0.85	20.3	23
Anacortes	68,301	11.14	0.28	0.85	2.7	4
Everett	43,726	8.15	0.10	0.85	0.7	0
Honolulu	40,043	12.80	1.61	0.85	17.5	16
San Francisco	32,762	8.94	2.37	0.85	18.0	21
Oakland	29,507	15.05	0.36	0.85	4.6	3
Port Townsend	20,352	3.34	0.43	1.9	2.7	3
Port Angeles	13,627	3.16	0.85	1.9	5.1	5
San Diego	7,090	2.29	3.68	1.9	16.0	18
Valdez	4,457	0.95	0.45	1.9	0.8	2
Anchorage	4,113	2.85	2.48	1.9	13.4	11
Kahului	3,892	1.15	0.91	5.0	5.3	4
Hilo	2,924	1.03	0.10	5.0	0.5	0
Olympia	2,920	0.45	0.10	5.0	0.3	0
Nawiliwili	2,828	0.48	0.71	5.0	1.7	3
Stockton	1,461	0.58	0.75	5.0	2.2	3
Kawaihae	1,312	0.28	0.50	5.0	0.7	2
Redwood City	1,048	0.16	0.25	5.0	0.2	1
Total	808,767	Not Used	Not Used	Not Used	199.6	205

identified that incorporated transits, ship factors and port factors into a Collision Prediction Model, and the model's predictions closely match historical data. One of the primary purposes of the CPM is to be able to predict collisions over some future time span and thus provide a basis for assessing alternatives designed to alleviate the collision problem. To assess the CPM's ability to predict, the CPM is used to forecast 1977 collisions and the forecast is compared with the actual number of collisions that occurred in 1977. For this forecast, no prior knowledge of the number of collisions is used.

Because of their immediate proximity, Los Angeles and Long Beach forecasts and historical results are combined. The evaluation of the CPM results is based on absolute value comparison and relative ranking tests. The impact of CPM accuracy in forecasting collisions is addressed in Section X.

Absolute Value Comparison

Table XXXVII presents the CPM forecasts for 1977 based on the derivation of the CPM equations and coefficients using the 1976 data base. Examination of Table XXXVII indicates that:

1) The CPM forecasted the total number of collisions within 10 percent of historical results.
2) Even without prior knowledge of 1977 collisions, 14 of 21 ports met the criteria established to derive CPM equations based upon historical results.
3) Ports which did not meet the criteria generally had a large change in the number of collisions between 1976 and 1977.

TABLE XXXVII. 1977 PREDICTIONS USING CPM
(CPM Based on 1976 Data Base)

Port	Transits	Ship Factor Predictions	π_{pt}	π_{pm}	Predicted Collisions	Historical Collisions
Seattle	118,554	21.01	0.95	1.0	20.0	24
Long Beach	60,090	17.69	0.29	0.57	2.9 } 23.7	8 } 20
Los Angeles	41,526	14.37	2.54	0.57	20.8	12
Tacoma	35,232	7.64	1.86	0.85	12.1	9
Anacortes	27,178	4.71	0.51	0.85	2.0	0
Everett	20,628	3.55	0.10	0.85	0.3	0
Honolulu	19,448	6.17	2.33	0.85	12.2	4
San Francisco	13,854	3.56	0.99	0.85	3.0	16
Oakland	9,984	6.59	0.60	0.85	3.4	0
Port Townsend	9,634	1.41	0.71	1.9	1.9	0
Port Angeles	7,024	1.23	1.49	1.9	3.5	0
San Diego	3,142	0.83	2.00	1.9	3.2	12
Valdez	1,394	0.31	0.69	1.9	0.4	0
Anchorage	1,570	1.20	3.20	1.9	7.3	2
Kahului	1,744	0.54	1.09	5.0	2.9	1
Hilo	1,266	0.43	0.10	5.0	0.2	0
Olympia	1,550	0.25	0.10	5.0	0.1	0
Nawiliwili	1,560	0.23	1.13	5.0	1.3	0
Stockton	478	0.21	1.15	5.0	1.2	0
Kawaihae	564	0.14	0.10	5.0	0.1	2
Redwood City	350	0.07	0.39	5.0	0.1	0
Totals	376,770	Not Used	Not Used	Not Used	98.9	90

The χ^2 test can be used as a measure of the discrepancy between observed and predicted collisions. One of the conditions for applying the χ^2 test is that the predicted number of events is at least equal to 5. Since many of the ports have predicted collisions less than 5, it is necessary to group ports. Table XXXVIII shows the ports that were grouped together and the χ^2 test. Ports were grouped generally on their location (e.g., San Francisco Bay, Puget Sound). Table XXXVIII shows that based on the χ^2 test, the CPM forecasts match historical results for large ports and groups of smaller ports.

Relative Ranking Comparison

The ranking test previously applied to the 1976 predictions is used to evaluate the CPM's ability to forecast the relative ranking of ports based on number of collisions. Table XXXIX shows this evaluation and demonstrates that the CPM is reasonably accurate in ranking ports (see Appendix F). Another test can be applied to measure the CPM's ability to rank ports. This test is the Spearman's formula for rank correlation (Reference 7). The values shown in Table XXXIX can be used to calculate Spearman's formula for rank correlation. The formula is:

$$r_{rank} = 1 - \frac{6\Sigma(\Delta')^2}{N(N^2 - 1)}$$

where Δ' = difference between ranks of corresponding values.

N = number of ports in the data.

From Table XXXIX, the value of Δ' is 317, and therefore r_{rank} = 0.76, thus indicating there is a marked relationship between CPM and

TABLE XXXVIII.

CHI-SQUARE TEST OF CPM FORECASTING ACCURACY

Port	Predicted Collisions	Historical Collisions	Δ	$\frac{(\Delta)^2}{\text{Predicted}}$
Seattle	20.0	24	+4	0.80
Long Beach/ Los Angeles	23.7	20	-3.7	0.58
Tacoma	12.1	9	-3.1	0.79
Hawaii San Diego Valdez	20.3	19	-1.3	0.08
Puget Sound San Francisco Anchorage (Less Tacoma and Seattle)	22.8	18	-4.8	1.01
Totals	98.9	90	-8.9	3.26

For 4 degrees of freedom and 0.01 level of significance, $\chi^2_{.99}$ = 13.3.

Since 13.3 > 3.26, we accept the hypothesis that the CPM forecasts approximate observed results for large ports and groups of smaller ports.

TABLE XXXIX. RELATIVE RANKING COMPARISON
(1977 Collisions)

Port	Historical Ranking (most to least)	CMP Ranking (most to least)	Δ'	$(\Delta')^2$	Δ Maximum Inverse	Δ^2 Maximum Inverse
Seattle	1	2	1	1	19	361
Los Angeles/ Long Beach	2	1	1	1	17	289
San Francisco	3	8	5	25	15	225
San Diego	4	8	4	16	13	169
Tacoma	5	3.5	1.5	2.25	11	121
Honolulu	6	3.5	2.5	6.25	9	81
Kawaihae	7.5	17.5	10	100	7	49
Anchorage	7.5	5	2.5	6.25	5	25
Kahului	9	8	1	1	3	9
Everett	15	17.5	2.5	6.25	1	1
Port Townsend	15	11.5	3.5	12.25	1	1
Redwood City	15	17.5	2.5	6.25	3	9
Port Angeles	15	8	7	49	5	25
Stockton	15	13.5	1.5	2.25	7	49
Valdez	15	17.5	2.5	6.25	9	81
Nawiliwili	15	13.5	1.5	2.25	11	121
Hilo	15	17.5	2.5	6.25	13	169
Olympia	15	17.5	2.5	6.25	15	225
Anacortes	15	11.5	3.5	12.25	17	289
Oakland	15	8	7	49	19	361
				$\Sigma 317$		$\Sigma 2660$

Relative Ranking Indicator $\frac{\Sigma(\Delta')^2}{\Sigma\Delta^2} = \frac{317}{2660} = 0.12$

historical rankings of ports.

Collision Prediction Model Accuracy Conclusions

The previous two subsections demonstrated that based on the amount of testing feasible at this stage, the Collision Prediction Model can forecast with reasonable accuracy the number of collisions for various Pacific Coast ports and the relative ranking of ports. Other conclusions that can be drawn are:

1) The accuracy of the model is heavily influenced by the span of time over which it is applied. The longer the time span the more accurate the results, since the data base is larger. For example, during the 12-month FY 1977 period, 11 ports had no collisions, whereas during the 15-month FY 1976 period, only 4 ports had no collisions.

2) The CPM is able to predict the relative ranking of ports on a single year basis with reasonable accuracy. The accuracy of the CPM to rank ports increases as the length of time increases. If the 1976 data base is included in the ranking, the relative ranking indicator decreases from 0.35 to 0.2.

3) The CPM Model should be used to predict results over an extended period of time (a minimum of one year, preferably more than one year). The use of the model over an extended period of time will average out large fluctuations in collisions from one year to another.

4) The required forecasting accuracy without prior knowledge of collision statistics must be established by evaluating

the impact of errors in CPM forecasts using benefit-cost analysis. This evaluation is conducted in Section X.

5) A method should be incorporated to update the CPM to reflect actual experience (e.g., the CPM model must be able to adapt 1977 historical results in order to predict future results more accurately). This method for updating the CPM is described in the next subsection.

6) Additional testing and verification of the model should be accomplished as further data becomes available.

Adaptive Updating of the Collision Prediction Model

To improve the CPM's ability to predict collisions for a wide range of ports over extended periods of time, a means must be incorporated to reflect the latest historical results. This is accomplished by incorporating additional data into the CPM, thus providing a filtering effect that tends to smooth out the impacts of large fluctuations in collisions for certain ports. This precludes the possibility of future predictions being biased by a limited amount of past data. This filtering effect tends to result in an "average" number of port collisions being predicted. It also results in increased CPM accuracy, particularly when applied over many years.

The methods chosen to allow dynamic updating of the CPM include use of a recursive weighted least squares solution to revise the port factor multipliers (π_p), exponential curve fitting with the additional data included to update the collision rate (λ_{ij}) as a function of ship

length, and continued application of a statistical test to define the ship factor contribution due to ship-type (π_{ij}).

Port Factors - Recursive Weighted Least Squares Solution

Figure 10 shows the approach used to update the port factors portion of the CPM. A recursive weighted least squares solution is applied to update the π_p multipliers (π_{pt} and π_{pm}). For the present time, each year's data are weighted equally. However, a means is provided to allow variable weighting of data. For example, this may be desirable if the most recent year's historical results warrant heavier weighting to reflect latest trends. The number of collisions can be expressed as

Z_k	=	$A\pi_p$	+	e
Historical Collisions		Predicted Collisions		Error

where

Z_k = historical number of collisions for ports for time period k.

A = ship factor and transits contribution to predicting collisions.

π_p = port factor multiplier, $\pi_p = \pi_{pt}\ \pi_{pm}\ \pi_{OTHER}$.

e = difference between predicted and historical collisions or error.

With the passage of each year, additional data became available. The additional set of equations is expressed as

$$Z_{k+1} = H_{k+1}\ \pi_p + e_{k+1}$$

where

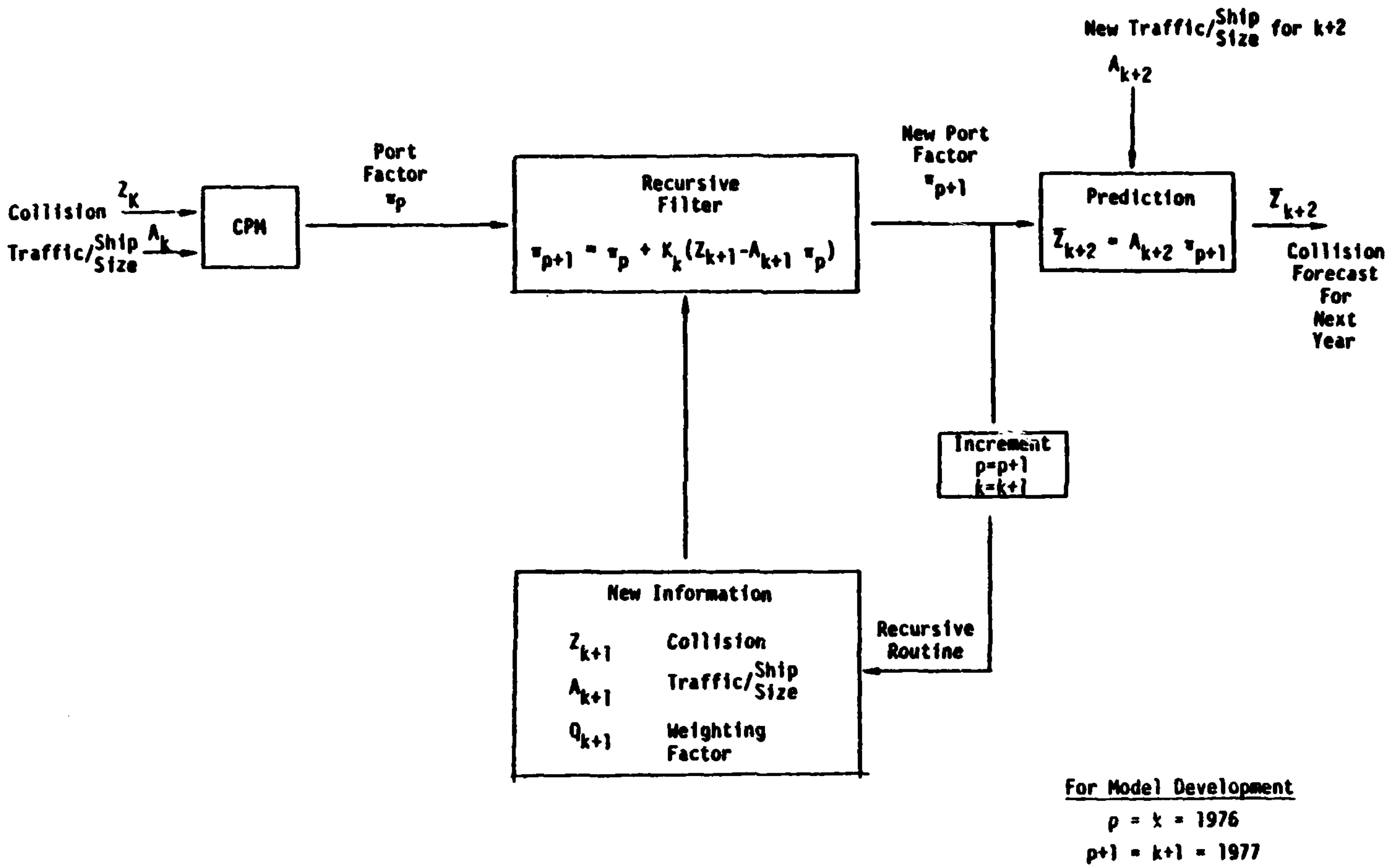

Figure 10. Adaptive Updating of Collision Prediction Model

Z_{k+1} = historical number of collisions for ports in time period k+1.

H_{k+1} = ship factor and transits contribution to predicting collisions in time period k+1.

π_p = original π_p multipliers.

e_{k+1} = difference between predicted and historical collisions for time period k+1 using π_p multipliers.

It is desirable to obtain a new estimate for π_p, denoted as π_{p+1}, which combines both sets of data and minimizes the error terms.

A recursive relation in modern control theory (Reference 8) is applicable to this situation. One obtains the results

$$\pi_{p+1} = \pi_p + K_k \{Z_{k+1} - H_{k+1} \pi_p\}$$

where

$$K_k = P_k H^T_{k+1} \{H_{k+1} P_k H^T_{k+1} + Q^{-1}_{k+1}\}^{-1}$$

and

$$P_k \triangleq (A^T Q A)^{-1}$$

Since the collision equations are scalar, matrix transpose and inversion are not required and scalar division is used. If we assume that Q = 1 (Equal weighting or $Q_k = Q_{k+1}$), the following equations apply

$$K = \frac{H}{H^2+A^2} \text{ (for } Q = 1)$$

$$\pi_{p+1} = \pi_p + K \{Z_{k+1} - H\pi_p\}$$

Table XL shows the results of using the above equations to upgrade the CPM. Table XL shows that all predicted collisions meet the criteria established in generating the CPM for $Q_k = Q_{k+1}$.

Impact of Weighting Factor

The equations presented in the previous subsection permit weighting of the data. This weighting might be desirable to reflect the latest information. For example, if a decision is made to weight the latest data more heavily, then

$$Q_{k+1} > Q_k$$

Arbitrary values can be substituted to reflect the degree of dependence on the latest data. For example, if $Q_{k+1} = 1.5\ Q_k$, the recursive filter equation will match the latest data more closely with some attendant loss of accuracy with regard to previous data. Table XL lists the results for three different values of Q_{k+1}. These values are $Q_{k+1} = Q_k$ (data weighted equally), $Q_{k+1} = 1.5\ Q_k$ (most recent data weighted more heavily), and $Q_{k+1} = 0.5\ Q_k$ (past data weighted more heavily). For the update of the CPM, a value of $Q_{k+1} = Q_k$ was chosen so that the two years of data are weighted equally.

Ship Factors-Collision Rate as a Function of Vessel Length (λ_{ij})

A revised exponential curve fit of collisions per transit and ship length is conducted to update the ship factor collision rate (λ_{ij}). The results of the curve fit conducted on the 1976/1977 data base are shown in Table XLI. A comparison of Tables XVIII and XLI shows that the equations are very similar, again demonstrating the validity of the model's approach.

TABLE XL. CPM RESULTS (BASED ON COMBINED 1976/1977 DATA BASE)

PORTS	PORT FACTOR BASED ON 1976 DATA USING CPM π_p	RECURSIVE FILTER GAIN $K = \frac{A_{K+1} Q_{K+1}}{A_{K+1}^2 Q_{K+1} + A_K^2 Q_K}$ K	WEIGHTING FACTOR $Q_{K+1} = C\ Q_K$ and Q_{K+1} Q_{K+1}	NEW PORT FACTOR BASED ON RECURSIVE FILTER π_{p+1}	ERROR BETWEEN 1976 + 1977 ACTUALS AND RECURSIVE LEAST SQUARE FIT $(Z_K + Z_{K+1}) - (A_K\pi_{p+1} + A_{K+1}\pi_{p+1})$	1976 and 1977 ACTUALS $Z_K + Z_{K+1}$
Los Angeles	1.45	0.0385 0.0266 0.045	1.00 0.50 1.50	1.11 1.21 1.05	-1.27 -4.1 0.4	29
San Francisco	0.85	0.0855 0.050 0.111	1.00 0.50 1.50	1.96 1.50 2.29	3.48 7.5 0.49	21
Redwood City	1.95	5.38 3.32 6.80	1.00 0.50 1.50	1.20 1.50 1.02	0.81 0.76 0.84	1
Oakland	0.51	0.0573 0.035 0.072	1.00 0.50 1.50	0.32 0.39 0.267	-1.79 -2.9 -1.0	3
Anacortes	0.43	0.0741 0.0449 0.095	1.00 0.50 1.50	0.28 0.34 0.238	0.88 0.2 1.3	4
Everett	0.09	0.1051 0.065 0.133	1.00 0.50 1.50	0.06 0.069 0.048	-0.46 -0.7 -0.4	0

TABLE XL. CPM RESULTS (BASED ON COMBINED 1976/1977 DATA BASE) (Continued)

PORTS	PORT FACTOR BASED ON 1976 DATA USING CPM π_p	RECURSIVE FILTER GAIN $K = \frac{A_{K+1} Q_{K+1}}{A_{K+1}^2 Q_{K+1} + A_K^2 Q_K}$ K	WEIGHTING FACTOR $Q_{K+1} = C\, Q_K$ and Q_{K+1} Q_{K+1}	NEW PORT FACTOR BASED ON RECURSIVE FILTER π_{p+1}	ERROR BETWEEN 1976 + 1977 ACTUALS AND RECURSIVE LEAST SQUARE FIT $(Z_K + Z_{K+1}) - (A_K \pi_{p+1} + A_{K+1} \pi_{p+1})$	1976 and 1977 ACTUALS $Z_K + Z_{K+1}$
Olympia	0.50	2.44 1.75 2.8	1.00 0.50 1.50	0.20 0.28 0.15	-0.09 -0.13 -0.07	0
Tacoma	1.58	0.06 0.04 0.075	1.00 0.50 1.50	1.39 1.46 1.35	1.04 0.01 1.67	23
Seattle	1.05	0.0206 0.013 0.025	1.00 0.50 1.50	1.09 1.08 1.10	-3.2 -2.5 -3.6	46
Port Townsend	1.35	0.247 0.149 0.32	1.00 0.50 1.50	0.88 1.07 0.75	0.06 -0.56 0.5	3
Port Angeles	2.83	0.24 0.14 0.31	1.00 0.50 1.50	1.98 2.33 1.72	-1.26 -2.37 -0.44	5
San Diego	3.80	0.29 0.17 0.39	1.00 0.50 1.50	6.40 5.28 7.28	3.34 5.9 1.33	18

TABLE XL. CPM RESULTS (BASED ON COMBINED 1976/1977 DATA BASE) (Continued)

PORTS	PORT FACTOR BASED ON 1976 DATA USING CPM π_p	RECURSIVE FILTER GAIN $K = \frac{A_{K+1} Q_{K+1}}{A^2_{K+1} Q_{K+1} + A^2_K Q_K}$ K	WEIGHTING FACTOR $Q_{K+1} = C\,Q_K$ and Q_{K-1} Q_{K+1}	NEW PORT FACTOR BASED ON RECURSIVE FILTER π_{p+1}	ERROR BETWEEN 1976 + 1977 ACTUALS AND RECURSIVE LEAST SQUARE FIT $(Z_K + Z_{K+1}) - (A_K \pi_{p+1} + A_{K+1} \pi_{p+1})$	1976 and 1977 ACTUALS $Z_K + Z_{K+1}$
Long Beach	0.17	0.029 0.020 0.036	1.00 0.50 1.50	0.32 0.27 0.35	0.02 1.67 -0.90	11
Honolulu	1.98	0.075 0.050 0.092	1.00 0.50 1.50	1.36 1.58 1.23	-1.49 -4.2 0.3	16
Anchorage	6.08	0.288 0.174 0.369	1.00 0.50 1.50	4.55 5.16 4.13	-1.98 -3.7 -0.76	11
Valdez	1.31	0.613 0.339 0.839	1.00 0.50 1.50	1.06 1.17 0.97	0.99 0.89 1.08	2
Nawiliwili	5.65	1.99 1.29 2.43	1.00 0.50 1.50	3.06 3.40 2.49	1.52 1.1 1.8	3
Kahului	5.45	0.814 0.52 1.00	1.00 0.50 1.50	3.87 4.44 3.51	-0.45 -1.1 -0.03	4

TABLE XI. CPM RESULTS (BASED ON COMBINED 1976/1977 DATA BASE) (Continued)

PORTS	PORT FACTOR BASED ON 1976 DATA USING CPM π_p	RECURSIVE FILTER GAIN $K = \dfrac{A_{K+1}\, Q_{K+1}}{A_{K+1}^2\, Q_{K+1} + A_K^2\, Q_K}$ K	WEIGHTING FACTOR Q_{K+1} C Q_K and Q_{K+1} Q_{K+1}	NEW PORT FACTOR BASED ON RECURSIVE FILTER π_{p+1}	ERROR BETWEEN 1976 + 1977 ACTUALS AND RECURSIVE LEAST SQUARE FIT $(Z_K + Z_{K+1}) - (A_K \pi_{p+1} + A_{K+1} \pi_{p+1})$	1976 and 1977 ACTUALS $Z_K + Z_{K+1}$
Kawaihae	0.50	3.57 2.38 4.29	1.00 0.50 1.50	7.39 5.10 8.77	-0.07 0.6 -0.46	2
Hilo	0.50	0.789 0.475 1.01	1.00 0.50 1.50	0.33 0.40 0.28	-0.34 -0.41 -0.29	0
Stockton	5.75	1.16 0.66 1.55	1.00 0.50 1.50	4.35 4.95 3.88	0.48 0.13 0.75	3

TABLE XLI. COMPUTATION OF SHIP FACTORS (λ_{ij})

(Combined 1976/1977 Data Base)

Ship Length, X (Midpoint Feet)	Number of Collisions	Transits	Collisions Per Transit, Y	Log Y	X Log Y	λ_{ij}
120	161	842,769	.000191	- 3.719	- 446.3	.000164
450	17	18,068	.000941	- 3.026	-1361.7	.00111
550	20	13,859	.00144	- 2.842	-1563.1	.00198
650	18	4,095	.00440	- 2.357	-1532.1	.00352
750	11	1,515	.00726	- 2.139	-1604.3	.0063
2520	227	880,306	Not Used	-14.083	-6507.5	Not Used

$\log Y_{SF} = -4.086 + (X)\,(0.0025193)$

$= (0.000082)\,(1.0058)^{X}$

Ship Factors - Ship-Type Multiplicative Factor (π_{ij})

The combined 1976/1977 data base provides an opportunity to refine the specific values for the ship-type multiplicative factor. Values based solely on the 1976 data base are presented in Table XXVI and a revised set of π_{ij} multipliers in Table XLII. The π_{ij} values are determined by dividing the historical collision rate (probability of collision, Table XXXIV) by the theoretical ship factor collision rate (Table XLI) for those length ships that show a statistical difference in collision rates. For this study, a statistical difference is demonstrated for ships greater than or equal to 700 feet, and therefore Table XLII lists values other than 1.0 for these vessels.

One observation is made in regard to the ship-type multiplicative factors. The revised ship-type multiplicative factors (Table XLII) when compared to the initial values (Table XXVI) are moving in the direction of the value 1.0. This means that when the 1977 data are combined with the 1976 data, the difference in collision rates for tankers and passenger/cargo vessels is less than for the 1976 data base. If this trend continues in the future, the statistical test will not show a significant difference, and the ship-type multiplicative factors will converge to 1.0.

Collision Prediction Model Summary

The methodology used to generate the Collision Prediction Model has been validated. The validation included using additional data bases for comparison of predicted and observed collisions. In addition, several techniques (such as the use of a recursive

TABLE XLII. REVISED SHIP-TYPE MULTIPLICATIVE FACTORS (π_{ij})
(Based on Combined 1976/1977 Data Base)

Length Category (feet)	Ship-Type i \ j	Passenger/ Cargo 1	Tanker 2	Other 3
0 < 400	1	1.0	1.0	1.0
400 < 500	2	1.0	1.0	1.0
500 < 600	3	1.0	1.0	1.0
600 < 700	4	1.0	1.0	1.0
≥ 700	5	3.66	0.39	1.0

weighted least squares solution) were implemented to allow a dynamic updating of the CPM to reflect later data and provide increased accuracy in predicting collisions. The final CPM equations based on latest available data are:

$$\text{Number of collisions} = \sum_{i=1}^{5} \sum_{j=1}^{3} \sum_{p=1}^{21} \underbrace{(0.000082)(1.0058)^{X}(\pi_{ij})}_{\text{Ship Factors}} \underbrace{(\pi_p)}_{\text{Port Factors}} \underbrace{(T_{ijp})}_{\text{Exposure Criteria}}$$

where X = ship length midpoints of 120, 450, 550, 650, and 750 feet associated with i^{th} categories 1 through 5 respectively.

π_{ij} = multiplicative factor to account for the contribution of ship-type j in relation to ship length category i (from Table XLII).

π_p = multiplicative factor for port factor contribution (from Table XL).

T_{ijp} = transits for length category i, ship-type j and port p.

The required forecasting accuracy without prior knowledge of collision statistics must be established by evaluating the impact of errors in CPM forecasts using benefit-cost analysis. This evaluation is conducted in Section X.

VIII. COLLISION REDUCTION METHODS

The Collision Prediction Model (CPM) predicts the number of collisions for Pacific Coast ports based on usage, ship and port factors. As discussed above, the impact of a change in ship or port factors is incorporated through the use of multiplicative factors. This section reviews briefly some of the available methods for reducing collisions. Section IX describes the methodology for determining the effectiveness of collision reduction methods, and Sections IX and X discuss the benefit-cost aspects of alternatives for reducing collisions.

Vessel Traffic Systems (VTS)

A Vessel Traffic System is defined by the Coast Guard as "An integrated system encompassing the variety of technologies, equipment and people employed to coordinate vessel movements in or approaching a port or waterway." (Reference 9). The objective of a Vessel Traffic System is to reduce the probability of vessel collisions while facilitating vessel movements. Significant research has been accomplished in this area. References 9 through 12, for example, provide excellent descriptions of the issues associated with Vessel Traffic Systems.

The elements of a Vessel Traffic System are: 1) Traffic Separation Scheme, 2) Vessel Movement Reporting System 3) Basic Surveillance, 4) Advanced Surveillance, and 5) Automated Advanced Surveillance Systems. The VTS elements listed above can be combined to form a system that defines the level of sophistication and type of

management. The different types of management include: 1) passive management which coordinates vessel traffic through indirect control of vessel movements by means of traffic separation schemes, 2) advisory management which coordinates vessel traffic by disseminating advice in the form of navigational, weather and vessel movement information, and 3) active management which coordinates vessel traffic through direct or positive control of vessel movements.

Many of the elements described above can be implemented in a variety of ways. For example, the normal surveillance technique in Vessel Traffic Systems is shore based radar. Other alternatives to shore based radar are: 1) shore based radar supplemented by shipboard radar transponders to identify the ship, 2) low light level television, 3) laser gating and illumination combined with low light level television to overcome background lighting saturating the low light level television camera, 4) passive acoustic, 5) active acoustic, 6) subsurface electromagnetic detection, 7) ultrasonic detection, 8) infrared detection, 9) navigation retransmission, and 10) automatic direction finding.

Collision Avoidance Radars

Vessels have used radar for navigation and collision avoidance for some time. Simple radars provide distance and bearing to vessels which can be used in conjunction with own ship's information to determine a closest point of approach (CPA) and time of closest point of approach (TCPA). Based on this information, the person in charge of the vessel may decide to change course and speed to avoid a

collision.

Collision avoidance involves not only the radar itself, but the radar installation, its operation, the interpretation of the radar's indications and the maneuvering action of the responsible persons. Studies concerning the collisions of radar equipped vessels indicate that (Reference 13):

1) Radar is not a cure-all for the ship collision problem.
2) Ship's officers find it difficult to understand the relative motion problem properly.
3) Plotting the other ship's movement to determine course, speed, and closest point of approach is not done in many cases.
4) Too small a course change is made and too late to avert the accident.
5) Good seamanship is not practiced from the time prior to the detection of the other vessel to the time of the accident.
6) The great majority of accidents are due to human error.

Modern collision avoidance radars are available to assist in avoiding collisions. These sophisticated radars employ computers and displays to assist in tracking, displaying and providing steering information to those persons responsible for avoiding collisions. These radars typically track many targets, provide warnings of possible collisions and provide trial course and speed changes that can be tested before action is taken.

Other Equipment

New equipment and improvements in existing equipment, other than radar, can assist in avoiding collisions. Navigational aids such as radio direction finders and satellite navigation schemes provide information as to location in order to prevent groundings and ensure safe navigation. Satellites can also be used to interrogate vessels at appropriate intervals to determine their location. Ship's equipment would respond automatically. The ship's response would be relayed to the ground station where the ship's location would be determined. The tracking center could alert the ship of potential navigational problems.

Fathometers or echo sounders can be installed on many ships to determine depth of water. The depth of water information can be used to determine not only that the vessel may be approaching a grounding situation but also to provide location information using bottom contour navigation.

Docking talk-back systems can be used particularly on large vessels to assist in the difficult task of docking and undocking. Good communications are probably one of the most important elements in avoiding collisions. Large vessels typically are assisted by tugboats, and therefore systems designed to improve communications among docking vessels, tugboats and harbor facilities should be beneficial.

Training

The necessity for proper training has always been recognized as a significant factor in preventing collisions. Since human error is

probably the major factor in collisions, the importance of training and maintaining qualifications cannot be overemphasized.

IX. BENEFIT - COST ANALYSIS

Determining the Effectiveness of Collision Reduction Methods

A methodology to examine the probable effects of alternatives to reduce collisions is proposed by W. A. Dunn, J. S. Gardenier and others (References 1 and 2). The proposed methodology can be used in conjunction with the Collision Prediction Model to define the effectiveness of various alternatives for reducing collisions in specific ports. References 1 and 2 describe the methodology and illustrate its applications by predicting the effectiveness of collision avoidance radar systems and conducting a post-implementation assessment of the effectiveness of a change in regulations concerning the use of bridge-to-bridge radiotelephones.

The proposed methodology develops a set of criteria, called a Casualty Analysis Gauge, to determine which collisions in a population are preventable by a particular collision reduction method. The steps necessary to use the proposed methodology are summarized below:

1. A particular method is selected for evaluation (e.g., collision avoidance radars or bridge-to-bridge radiotelephones).
2. A simple logical model of a safe passing of vessels is developed.
3. A Casualty Analysis Gauge is developed requiring a set of questions to be answered yes or no (see Figure 11).
4. Based on a sample of U. S. Coast Guard marine casualty reports, the Casualty Analysis Gauge is tested to assure that the questions can be answered.

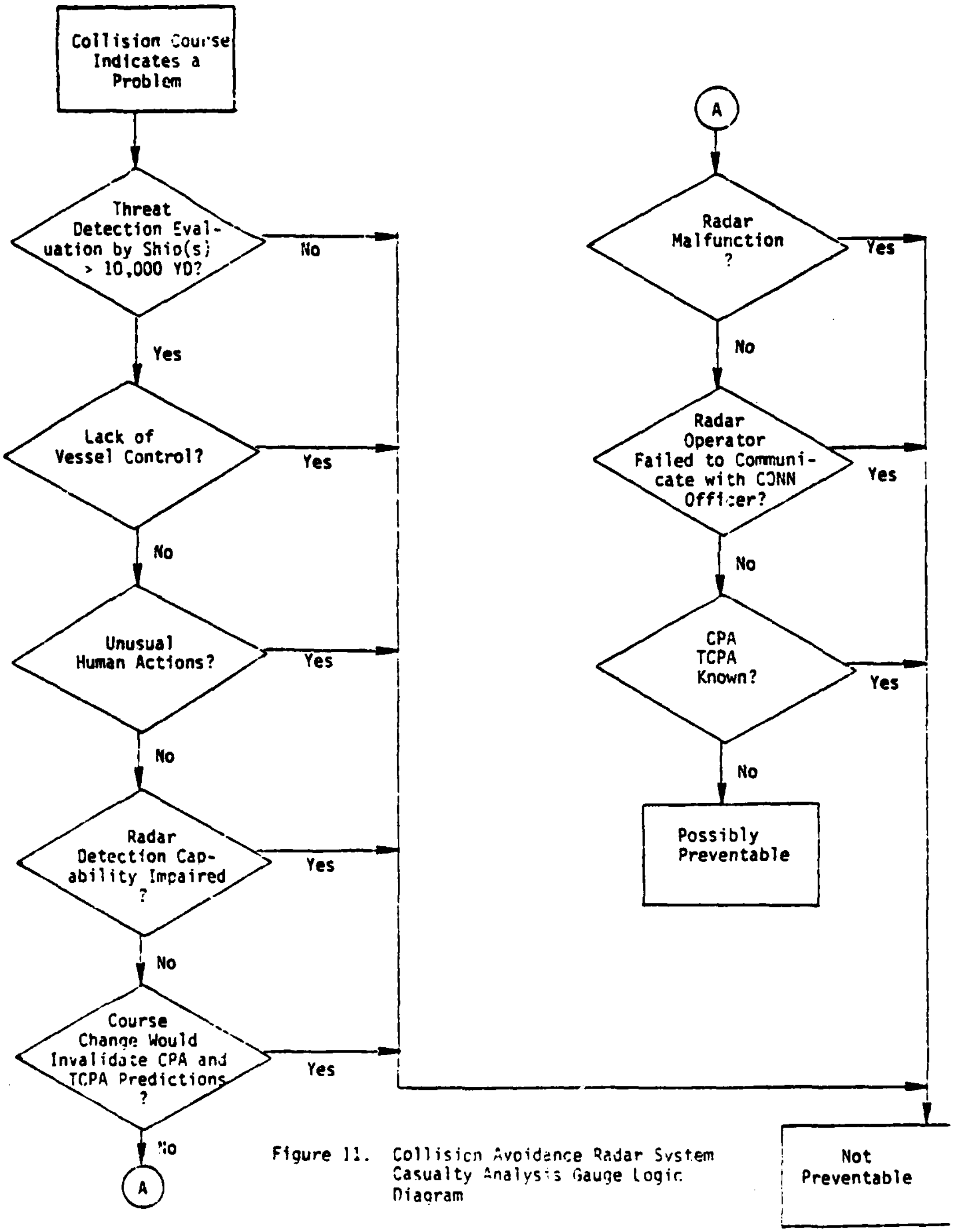

Figure 11. Collision Avoidance Radar System Casualty Analysis Gauge Logic Diagram

5. The objectivity of the gauge is tested by measuring the agreement rates of at least two independent evaluators statistically. Significant disagreements establish that the questions are ambiguous or that the reports do not contain clear evidence on certain points. Over ten percent disagreement is considered significant.
6. The Casualty Analysis Gauge is revised/clarified as necessary to arrive at an acceptable agreement rate.
7. The full set of appropriate casualty reports is read by two or more reviewers. Statistical agreement measures are taken on the final results.

<u>Example Results</u>

Using the procedure described above, Coast Guard personnel estimated the extent to which collision avoidance radars might be expected to reduce collisions involving vessels over 10,000 gross tons that are subject to U. S. Coast Guard jurisdiction (Reference 2). Based on 100 percent sampling of casualties involving vessels over 10,000 gross tons during the period 1970-1974, the following conclusions were drawn:

1. Collision avoidance radars definitely could not prevent some collisions.
2. Possibly somewhere between 9 and 13 percent of collisions (excluding groundings) could be prevented by such a system.

The methodology described is directly applicable for use in conjunction with the Collision Prediction Model generated during this

research, since the above system determines a multiplicative factor (percent reduction) by ship category (in this case ship size).

Benefits from Reduced Collisions

The U. S. Coast Guard casualty reports include parameters that are invaluable in establishing the cost of collisions. These parameters include the reported estimated dollar losses to vessels, cargo and other properties; the number of passengers, crew, workmen and others killed; and the number of passengers, crew, workmen and others injured. Based on the dollar losses reported, statistical analysis can be accomplished for various types and sizes of ships to determine such values as mean, maximum, and minimum losses and dispersions. Tables XLIII and XLIV show the computer statistical evaluations for dollar losses. For this research, the cost savings (benefits) resulting from various collision avoidance alternatives are determined by multiplying the average cost of collisions times the number of collisions prevented by the selected alternative. The values of lives saved, injuries prevented, reduction in pollution, and reduction in operating losses during vessel and property repairs are not included in this analysis as they are an extension of the basic cost analysis. Specific applications of this research should take these values into account. Less tangible benefits, such as reduction in the probability of a major marine catastrophe, also exist and could be taken into account.

Cost of Collision Avoidance Methods

The cost of various collision avoidance methods involves

TABLE XLIII. SUMMARY OF AVERAGE COLLISION COSTS ($K)*
(Based on 1976/1977 Data Base)

Length (Feet)	All Vessels	Passenger Cargo	Tanker	Tug/ Towboat	Non Self-Propelled	All Vessels Except Fishing
< 400	17.2	28.7	24.7	10.0	20.8	17.2
400 < 500	45.6	47.4	32.0	-	46.4	45.8
500 < 600	55.9	45.0	119.6	-	20.6	55.9
600 < 700	102.9	78.0	139.7	-	-	102.9
≥ 700	212.0	65.0	445.5	-	-	212.0

*Includes loss to vessel, loss to cargo, and loss to other

TABLE XLIV. SUMMARY OF AVERAGE COLLISION COSTS BREAKOUT ($K)
(Based on 1976/1977 Data Base)

Length (Feet)	Vessel Loss	Cargo Loss	Other Loss
< 400	10.2	2.6	4.4
400 < 500	37.6	1.5	6.5
500 < 600	44.3	5.2	6.4
600 < 700	57.4	0.2	44.8
≥ 700	119.4	47.5	44.2

identifying the various costs associated with obtaining (including developing), implementing and maintaining the particular collision avoidance method being evaluated.

Benefit-Cost Analysis

The method chosen in this research for conducting benefit-cost analysis is that of determining Net Present Value, taking into account the cost and benefits predicted over the operating period of the system. The next section gives examples to demonstrate how the method is applied.

X. APPLICATION OF DEVELOPED CONCEPTS

The Collision Prediction Model provides a means to conduct benefit-cost analysis from several viewpoints. First, the analysis can be conducted from a port viewpoint for federal, state or local agencies that are interested in evaluating various collision reduction methods that could be installed in ports. Second, the analysis can be conducted from a ship viewpoint for shipbuilders or owners who are interested in evaluating ship installed collision reduction methods. Third, the analysis can be conducted from a total effectiveness viewpoint to evaluate the impact of collision reduction methods for ports or fleets of ships. In addition, the mathematical model can be used for tradeoffs to predict the number of collisions for a fleet of ships of various types and sizes to accomplish similar jobs (e.g., determine the most cost effective fleet of ships from a collision avoidance viewpoint to transport oil from Alaska to the West Coast).

The developed concepts are applied as follows:

1. Prediction of the number of collisions.
    a. Identification of the ports involved.
    b. Estimation of the number of transits for various type ships.
    c. Determination of the port factors from Table XL.
    d. Identification of the other π multipliers if known, otherwise assume a value of 1.0.
    e. Calculation of the predicted number of collisions for various size ships using the Collision Prediction Model.

2. Evaluation of the impact of collision reduction methods.

   a. Determination of a multiplicative factor (π) for collision reduction methods

      (e.g., $\pi_{\substack{\text{collision}\\\text{avoidance}\\\text{radar}}} = 0.90$).

   b. Calculation of the predicted number of collisions.

   c. Determination of the number of predicted collision reductions.

3. Benefit-cost analysis.

   a. Identification of the life cycle costs associated with collision reduction methods.

   b. Determination of the benefits arrived at from the reduced number of collisions using historical values for costs of collisions.

   c. Inclusion of other cost benefits that can be identified.

   d. Evaluation of the collision reduction methods by calculating the Net Present Value. (The system with the highest NPV is theoretically the most cost effective.)

Example - Port Viewpoint

The proposed installation of a Vessel Traffic System (VTS) illustrates the use of the methodologies developed. Assume that a VTS is proposed for installation in the Los Angeles/Long Beach area. In addition, assume that a 5 percent increase in traffic is predicted each year for the next 10 years and that the ratio of different size vessels remains the same. The one-time cost of

installing a Vessel Traffic System is estimated at $500,000 with annual operative and maintenance costs of $300,000 with 7 percent annual inflation. Assume that the cost of capital is 7 percent.

Table XLV shows the predicted collisions, reduction in collisions as a result of installing a VTS, and the cost savings resulting from reduced collisions for the ten-year period 1978 through 1987. The last column of Table XLV is calculated by including a 5 percent increase in traffic per year (therefore, a 5 percent increase in collisions and collision reductions per year) and a 7 percent annual increase in cost of collisions (inflation) to arrive at an approximate net 12 percent increase in collision cost savings per year over 1978.

Based on the assumed cost of installing, operating and maintaining the VTS, benefit-cost analysis using Net Present Value is conducted. The NPV method allows a comparative ranking of several alternatives and also permits a determination of the cost effective alternatives. However, even though an alternative may have a negative Net Present Value, additional factors such as reduced risk for catastrophic events may still lead to the conclusion that the alternative is "worthwhile."

Figure 12 is used to show the Net Present Value of the proposed VTS for the Los Angeles/Long Beach area. The line marked baseline costs shows the Net Present Value based on the historical reported cost of collisions for 1976 and 1977 collisions. If the real costs are twice those reported, a positive trend in the NPV will occur. This is shown in line B of Figure 12. The real cost of collisions is probably many times the cost reported.

The real cost of collisions should account for such factors as

TABLE XLV. SUMMARY OF COLLISION COSTS FOR LOS ANGELES/LONG BEACH AREA

Ship Length (feet)	(a) 1977 Traffic	(b) 1978 Traffic (b) = 1.05 (a)	(c) 1978 Cost Per Collision ($K) (Table XLIII Costs Inflated 7%)	(d) Number of Collisions Predicted For 1978	(e) 1978 Reduction in Collision * (e) = 0.25 (d)	(f) 1978 Cost Savings ($K) (f) = (c)X(e)	(g) Cost Savings $K 1978-1987
< 400	94,818	99,559	18.4	10.39	2.60	47.8	853.2
400 < 500	2,752	2,889	48.4	2.47	0.62	29.9	533.7
500 < 600	2,562	2,691	59.8	3.89	0.97	58.2	1,038.8
600 < 700	856	899	110.1	2.29	0.57	63.0	1,124.5
≥ 700	622	653	226.8	4.03	1.01	228.5	4,078.5
Totals	101,610	106,691	463.5	23.07	5.77	427.4	7,628.7

*Assumes a VTS will reduce collisions by 25 percent.

lives lost, injuries incurred, pollution costs other than cleanup, and costs associated with operating losses during vessel and property repairs. For example, a vessel might collide with a railroad bridge making it unusable for several weeks. The costs associated with repairing the bridge and the added costs of lost revenues incurred while operating without the use of the bridge should be included in the cost of the collision. The costs reported to the Coast Guard do not include these added costs or lost revenues.

From Curve A of Figure 12, the VTS is shown to cost less than the attendant savings from reduced collisions in approximately three years. If the real cost of collisions is more than approximately two times that reported (Curve B), the Net Present Value is positive after the first year of operation.

The example given is based strictly on both the cost of installing, operating and maintaining the VTS and the cost savings associated with reduced collisions. Other items such as injuries, deaths, and pollution could be converted to costs and included in the analysis.

Example - Ship Viewpoint

A second example illustrates how a ship owner could evaluate the benefits associated with installation of a collision avoidance radar. The model is based on ships entering and leaving ports and does not address the additional benefits associated with open ocean or coastal transiting.

For this example, assume that a ship company is contemplating installing collision avoidance radars on all its ships. Assume also that the purchase and installation costs are $50,000 per ship and that

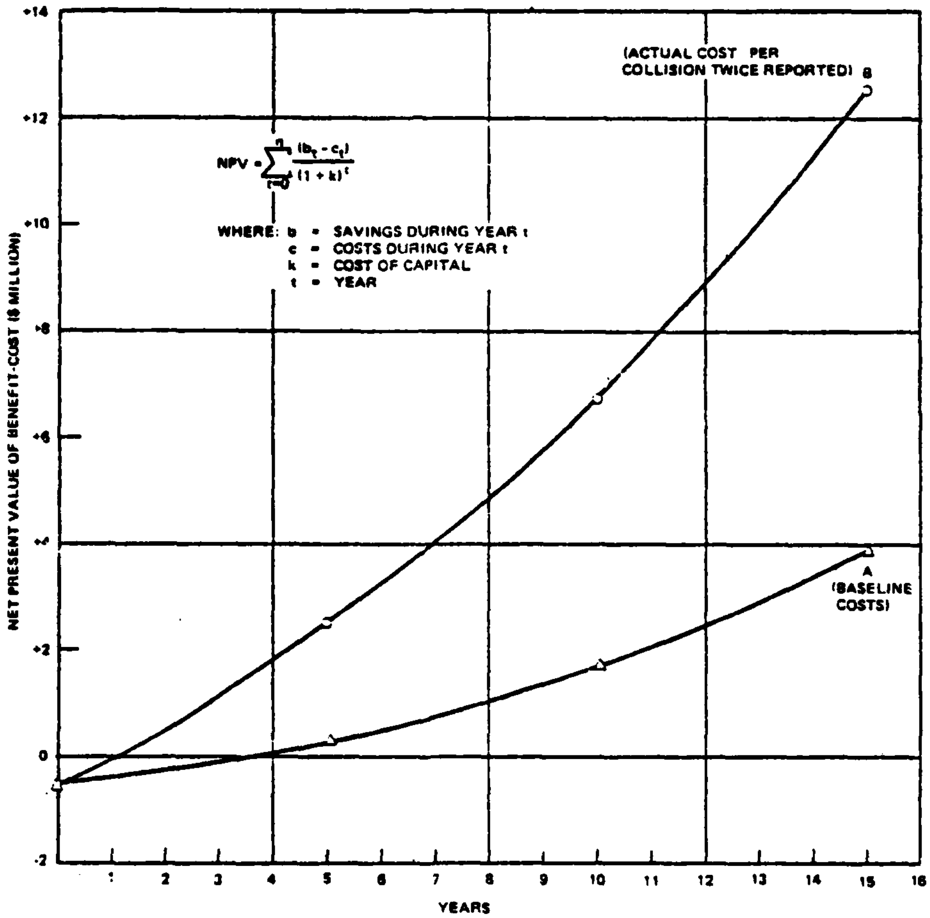

Figure 12. Hypothetical Evaluation of Proposed VTS for Los Angeles/Long Beach

annual operative and maintenance costs over and above that for the existing radar are $2,000. Assume the fleet of ships consists of:

100 ships with lengths less than 400 feet

25 ships between 400 and 500 feet in length

25 ships between 500 and 600 feet in length

5 ships between 600 and 700 feet in length

2 tankships greater than 700 feet in length

Furthermore, assume that Table XLVI lists the ports the ships will be frequenting and the expected number of port visits. Assume that the cost of collisions is the same as in the previous example.

Finally, assume that a multiplier equal to 0.9 has been established using the method described in Section IX.

Based on initial costs of $7,850,000 ($50,000 per ship for 157 ships), annual operating costs of $314,000 ($2,000 per ship for 157 ships) and a net savings per year of $77,950, the owners should conclude it is not cost effective to outfit their entire fleet of ships with shipboard collision avoidance radar (see Tables XLVII and XLVIII).

Further analysis could be conducted to determine whether or not it might be cost effective to outfit any of their ships. Evaluation for ships less than 600 feet shows that the annual operating costs exceed the expected savings per year, thus ruling out cost effective installation. However, Table XLVIII and Figure 13 show that for the greater than 700 foot category, collision avoidance radars are cost effective after approximately fifteen years of operation. Thus, the ship company owner or board of directors may decide to install collision avoidance radars in the largest ship category. Figure 13 also shows that if the real cost of collisions is twice that reported, the collision avoidance

TABLE XLVI. SHIP USAGE PER YEAR

Length Ship (feet)	Number of Ships	Port Visits Per Ship Per Year			Total Transits (2 Way)		
		Los Angeles	Seattle	Honolulu	Los Angeles	Seattle	Honolulu
< 400	100	16	16	16	3200	3200	3200
400 < 500	25	16	16	16	800	800	800
500 < 600	25	16	16	16	800	800	800
600 < 700	5	14	14	14	140	140	140
≥ 700	2	14	14	14	56	56	56

TABLE XLVII. SUMMARY OF COLLISION AND COST SAVINGS

Ship Length (feet)	Predicted Collisions						Reductions in Collisions		1978 Cost Savings ($)
	Los Angeles		Seattle		Honolulu		$\pi_{CAR} = 0.9$		
	1 Year	5 Years	1 Year	5 Years	1 Year	5 Years	1 Year	5 Years	
< 400	0.58	2.90	0.54	2.70	0.71	3.55	0.18	0.90	3,310
400 < 500	0.99	4.95	0.91	4.55	1.21	6.05	0.31	1.56	15,000
500 < 600	1.76	8.80	1.63	8.15	2.15	10.75	0.55	2.77	32,890
600 < 700	0.55	2.75	0.51	2.55	0.35	1.75	0.14	0.71	15,410
≥ 700	0.15	0.75	0.14	0.70	0.19	0.95	0.05	0.24	11,340
Totals	4.03	20.15	3.73	18.65	4.61	23.05	1.63	8.20	77,950

TABLE XLVIII. COST SAVINGS IN SHIP VIEWPOINT EXAMPLE

Ship Length (feet)	1978 Average Cost of Collision ($K)	Cost Savings (1978) ($K)	Annual Operating Costs (1978) ($K)	Net Present Value (7% Cost of Capital)		
				Install	10 Years (1978 - 1987)	15 Years (1978 - 1992)
< 400	18.4	3.31	200	-5,000,000	Never Positive (Negative Slope)	
400 < 500	48.4	15.00	50	-1,250,000	Never Positive (Negative Slope)	
500 < 600	59.8	32.89	50	-1,250,000	Never Positive (Negative Slope)	
600 < 700	110.1	15.41	10	- 250,000	-200,000	-175,000
≥ 700	226.8	11.34	4	- 100,000	- 38,000	- 4,000

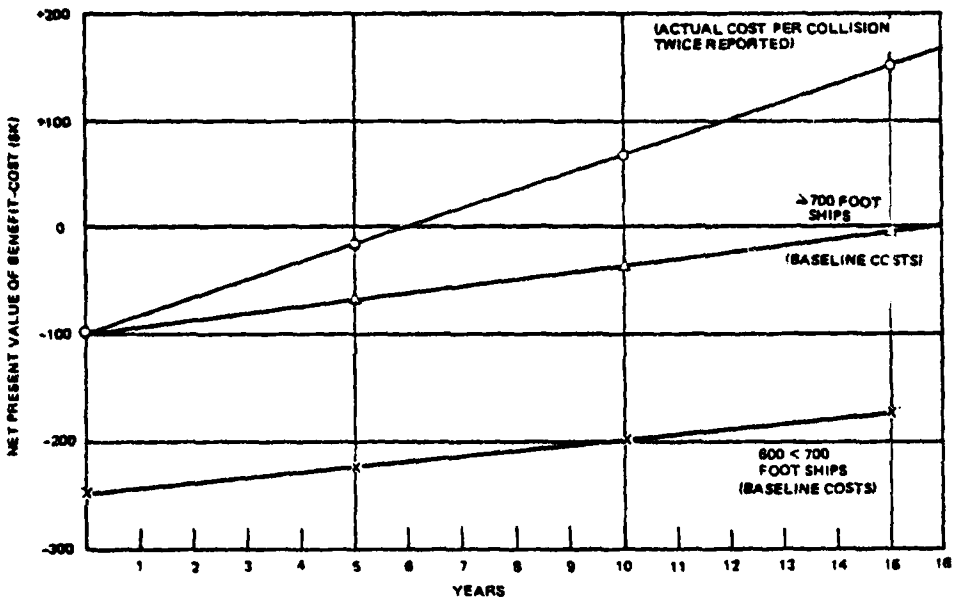

Figure 13. Hypothetical Evaluation of Collison Avoidance Radars

radar is cost effective for the largest ship category after six years of operation.

Parametric Application

The Collision Prediction Model in conjunction with benefit-cost analysis is able to determine the impact of varying parameters. This feature can be used to conduct sensitivity analysis which can be useful if there is a range of values that certain parameters could have. For example, some of the parameters that could easily have a range of values are cost of collisions, collision rates for various ship lengths, cost of alternatives to reduce collisions, the cost of capital, and the effectiveness of various collision reduction methods. This subsection explores the use of sensitivity analysis by varying certain important parameters.

The port viewpoint example previously discussed provides a basis for conducting sensitivity analysis. In that example, analysis was conducted based on the cost of collisions as reported to the Coast Guard and with the cost of collisions assumed to be twice that reported to the Coast Guard. For this example, assume that the cost of collisions can have the following multiples of the reported cost of collisions: 0.5, 1.0, 2.0, and 4.0. Furthermore, assume that the effectiveness multiplicative factor (π_{VTS}) can have the following values: 0.60, 0.75, and 0.90. Assume that the remaining parameters (cost of capital, Vessel Traffic System's installing and operating costs, and inflation) are the same as for the port viewpoint example with the exception that the combined percent increase in traffic and inflation rate result in exactly a 12 percent increase in collision cost savings per year.

Figure 14 demonstrates the impact of varying the cost of collisions while maintaining all other parameters constant. Examination of Figure 14 shows that the Net Present Value is very sensitive to the cost of collisions. Since it is highly likely that the actual cost of collisions is higher than the reported costs, the potential benefits of installing a Vessel Traffic System could be many times that shown based on the cost of collisions as reported to the Coast Guard.

Figure 15 demonstrates the impact of varying the effectiveness of the Vessel Traffic System and the cost of collisions. Examination of Figure 15 shows a significant impact of varying either the effectiveness of the collision avoidance technique or the cost of collisions.

Further analysis could be conducted by varying other parameters. These examples are intended to demonstrate the ability of the Collision Prediction Model in conjunction with benefit-cost analysis to conduct sensitivity analysis.

Accuracy of Collision Prediction Model

The Collision Prediction Model is used to forecast collisions based upon estimates of traffic type, traffic quantity and port parameters. A primary purpose of this research is to develop methods that will allow various agencies to identify trends and establish priorities in alleviating the ship collision problem. Since the CPM forecasts collisions, there will be errors between forecasts and future collision statistics. The question comes up, "How accurate must the Collision Prediction Model be in order to be useful?"

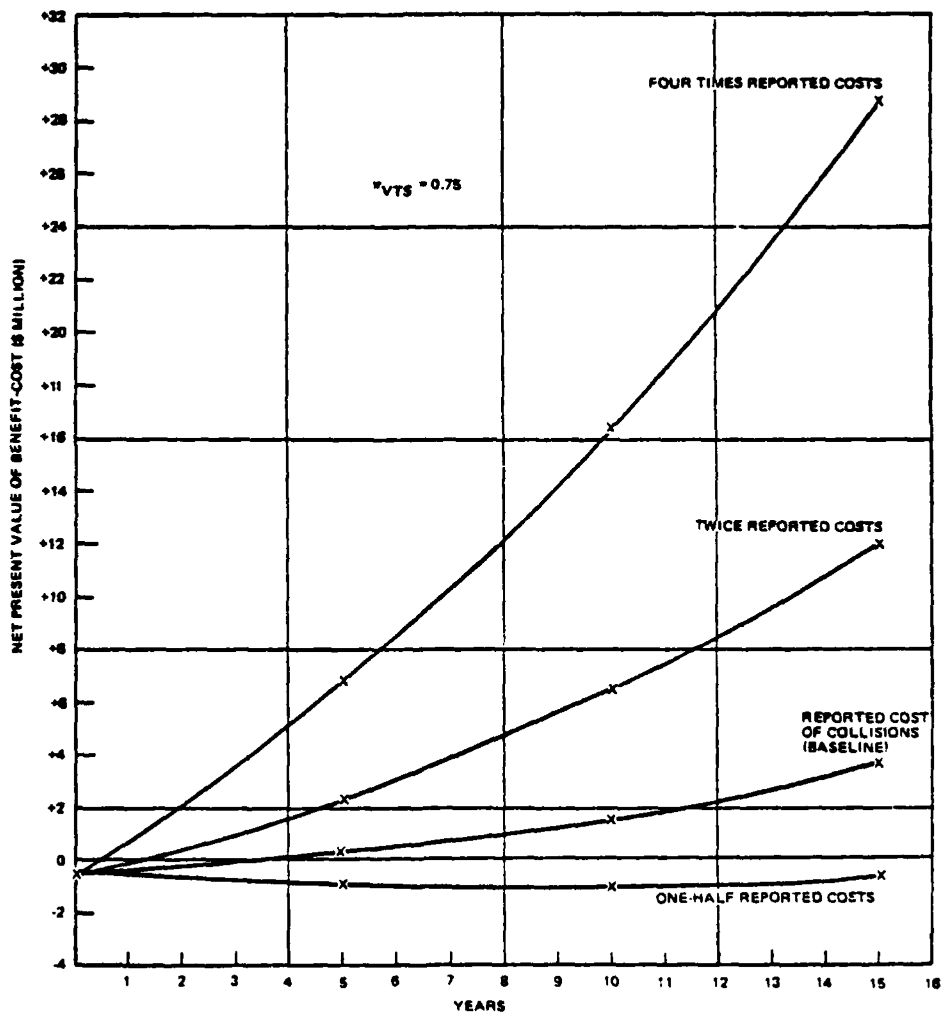

Figure 14. Impact of Varying Cost of Collisions on VTS Example

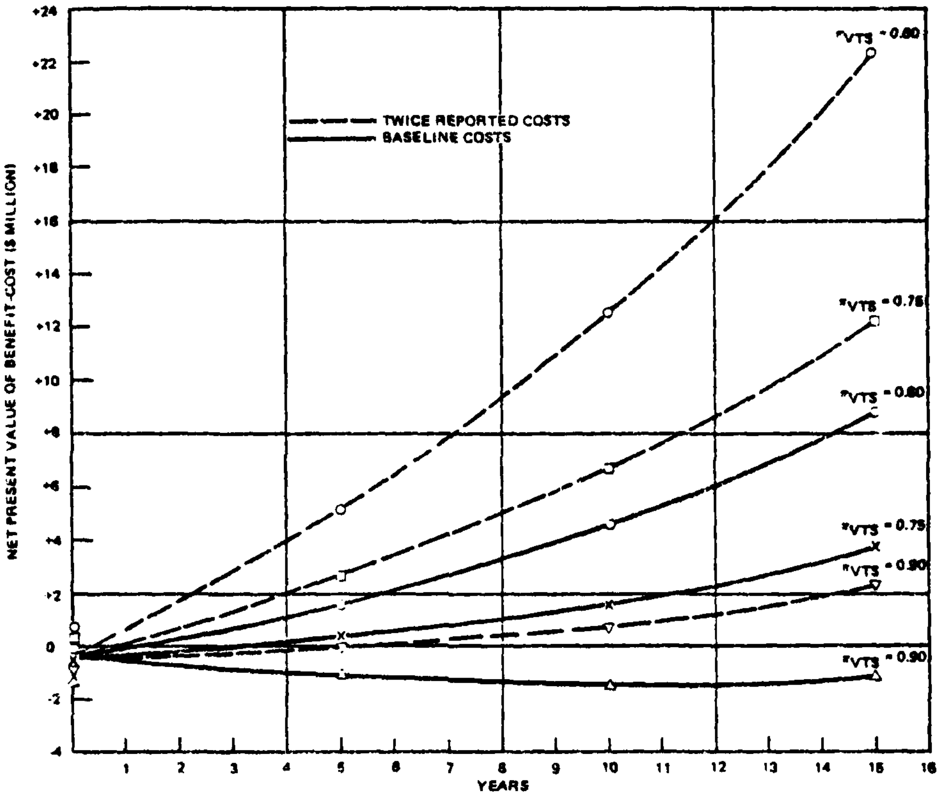

Figure 15. Impact of Varying Cost of Collisions and Effectiveness of VTS

This subsection examines that question.

Relative Ranking

The Collision Prediction Model allows forecasting the relative ranking of ports. Ports can be assigned collision risk priorities based on number of collisions, size of ships involved in collisions and the type of ships involved in collisions for very large size ships. This risk assignment can be used to identify priorities in considering what collision reduction alternatives should be considered and where.

In addition, risk assignment can be used to identify low risk ports where collision avoidance is sufficiently low to warrant no further effort. This could be helpful to shipping companies to establish traffic routes and to provide a basis for setting maritime shipping rates. On the other hand, marine insurance companies could use collision forecasting to develop appropriate rates for different traffic routes. The Collision Prediction Model has been shown to be fairly accurate in establishing relative ranking of ports (see Section VII). As the model develops and incorporates additional data, the CPM should become more accurate.

Forecasting Number of Collisions

The Collision Prediction Model provides a method to forecast the number of collisions for specific ports. As shown in Table XXXVII, there were errors between 1977 forecasts and 1977 historical results. The Vessel Traffic System example is used to analyze the impact of errors in forecasting collisions.

The 1977 forecasted collisions for Los Angeles were 20.8 and

and for Long Beach 2.9. The actual collisions were 8 for Long Beach and 12 for Los Angeles. The combined forecasted collisions are therefore 23.7 while the actual combined collisions are 20. This represents a combined 19% error for the Collision Prediction Model. Overestimating collisions results in an optimistic estimate of collision cost savings. The 19% error in forecasting collision results in a 19% error in the cost savings for 1978. Therefore, the 1978 cost savings would be $346,190 instead of $427,400 (see Table XLIV). Figure 16 shows the impact of a 19% error on forecasting collisions for the Vessel Traffic System example. Evaluation of Figure 16 reveals that a 19% error in the forecasting accuracy of the Collision Prediction Model would result in the Vessel Traffic System reaching a positive Net Present Value after about 6 years of operation as opposed to approximately 3.5 years. The change from 3.5 to 6 years would probably be regarded as very minor and therefore for this particular example a 19% error forecasting accuracy would be insignificant.

Figure 14 can be used to show the impact of other percent errors in forecasting collisions. Substitution of a percent error in forecasting collisions for the "reported cost" analyses would give identical results. For example, the line labeled one-half reported costs could represent a 50% underestimation of collisons. The line labeled twice reported costs would represent a 100% overestimation of collisions.

The impact of CPM forecasting accuracy should be evaluated by sensitivity analysis for any particular example. As shown by the

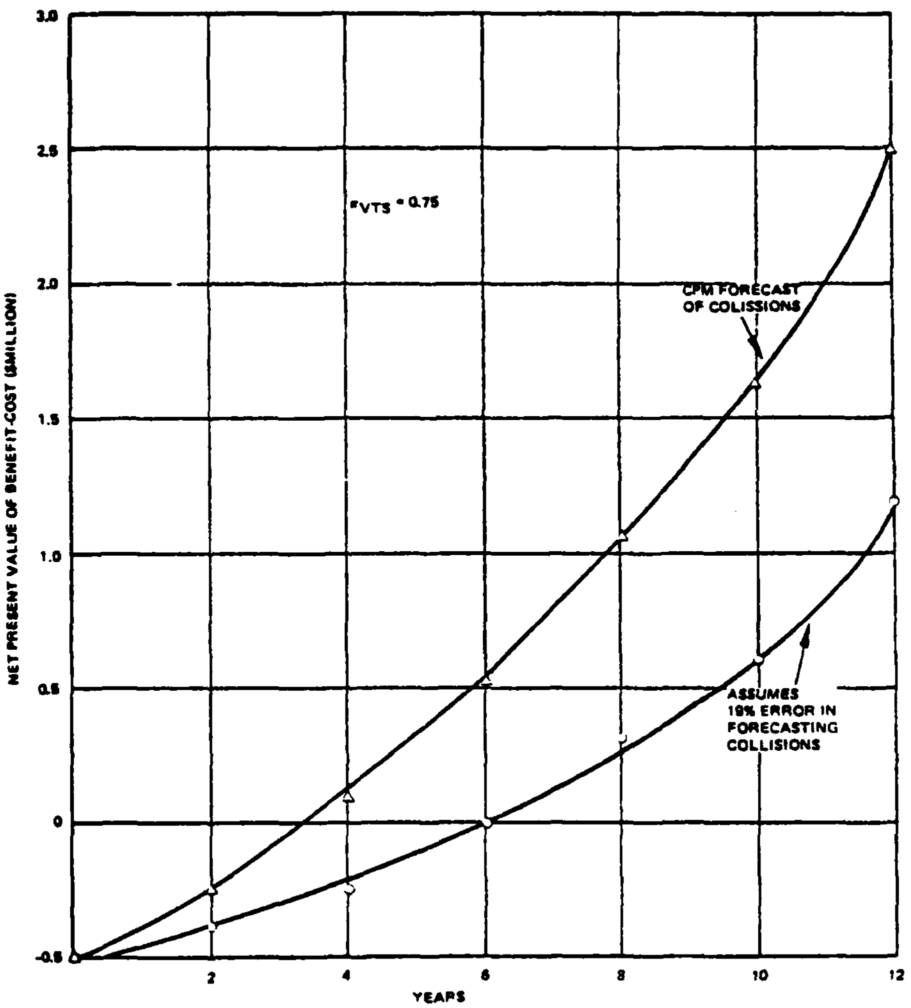

Figure 16. Impact of Collision Prediction Model Accuracy

Vessel Traffic System example, a 19% error was insignificant. Errors many times greater than 19% may not have a significant impact depending on the collision avoidance method being evaluated.

Collision Prediction Model Conclusions

Several conclusions can be drawn concerning the Collision Prediction Model based on the amount of testing which was feasible at this stage. These are:

1) The Collision Prediction Model is a useful tool to forecast collisions for ports.
2) It can be used to rank ports relatively.
3) The model, in conjunction with benefit-cost analyses, can be used to assess alternatives for reducing ship collisions.
4) Sensitivity analysis can be conducted to bound the problem and provide insight to the decision maker based upon quantitative terms.
5) The precise accuracy of the Collision Prediction Model is less important than its ability to identify trends and establish bounds.
6) Additional testing, verification and updating of the model should be accomplished as further data become available.

XI. SUMMARY AND EVALUATION

This research provides a methodology to evaluate the vessel collision problem, thus supplying marine agencies a quantitative technique to aid decision making. The methodology developed offers a practical means whereby agencies can identify trends and priorities in approaching the vessel collision problem. The three major elements are: 1) a Collision Prediction Model, 2) a method using a Casualty Analysis Gauge to determine the effectiveness of various collision avoidance methods, and 3) benefit-cost evaluation including sensitivity analyses.

The Collision Prediction Model is developed to predict ship collisions in ports and to evaluate the parameters for Pacific Coast ports. The Collision Prediction Model is based on ship factors, port factors and exposure criteria. Ship collisions can be predicted for a given port by estimating the magnitude of traffic, types of vessels, and sizes of vessels. Provisions for dynamic updating of the model are defined to improve the model's ability to predict collisions for a wide range of ports over extended periods of time. The methods chosen to allow dynamic updating of the Collision Prediction Model include use of a recursive weighted least squares solution, exponential curve fitting, and statistical tests.

Computer programs on the Dartmouth Time Sharing System were used to sort, tabulate and analyze statistically the massive amount of collision data. Several sources of data from the U. S. Coast Guard and Army Corps of Engineers were invaluable to this research. However, data limitations prevented identification of certain

factors (such as ship nationality) and their specific contribution to ship collisions. To account for future identification or other specific factors and to permit incorporation of later changes in port or ship characteristics, the model has been constructed in an expansible form. In this manner, the impact of a new feature, such as the installation of a Vessel Traffic System in a particular port, can be included when predicting collisions for a given port.

A Casualty Analysis Gauge (References 1 and 2) is proposed to determine which collisions in a population are preventable by a particular collision reduction method. This method determines multiplicative factors for use with the Collision Prediction Model to determine the reduction in collisions.

The Net Present Value method is used for benefit-cost analysis. The New Present Value method determines which alternatives are cost effective and allows a ranking of different alternatives.

The mathematical methods developed provide a quantitative basis for evaluating alternatives to reduce ship collisions. Inherent in the Collision Prediction Model is the ability to accomplish sensitivity analyses. Sensitivity analyses are conducted to identify the sensitivity of key parameters which influence the Collision Prediction Model accuracy. In many cases the accuracy of forecasting collisions is not critical. The sensitivity analyses allow certain critical items to be bounded (such as the number of years until the alternative is cost effective).

Some of the research that derived the Collision Prediction Model was accomplished under Coast Guard Contract (CG-83, 886-1E) to

University of California, Los Angeles. Agencies that could benefit from the proposed analytical approach include federal agencies such as the United States Coast Guard and Army Corps of Engineers, local agencies such as port harbormasters and pilot associations, shipping and shipbuilding companies and insurance companies covering ships and ports.

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APPENDIX A - CORRELATION BETWEEN SHIP DRAFT AND LENGTH

A study was made by Sciences Application Incorporated in which they deduce a correlation between draft and waterline length. The correlations derived in their study (Reference 4) were used during this research to assist in determining transit information as a function of ship length and type. Figures A-1 through A-6 show the correlation between draft and waterline length for tanker, passenger, cargo, tug and barge vessels.

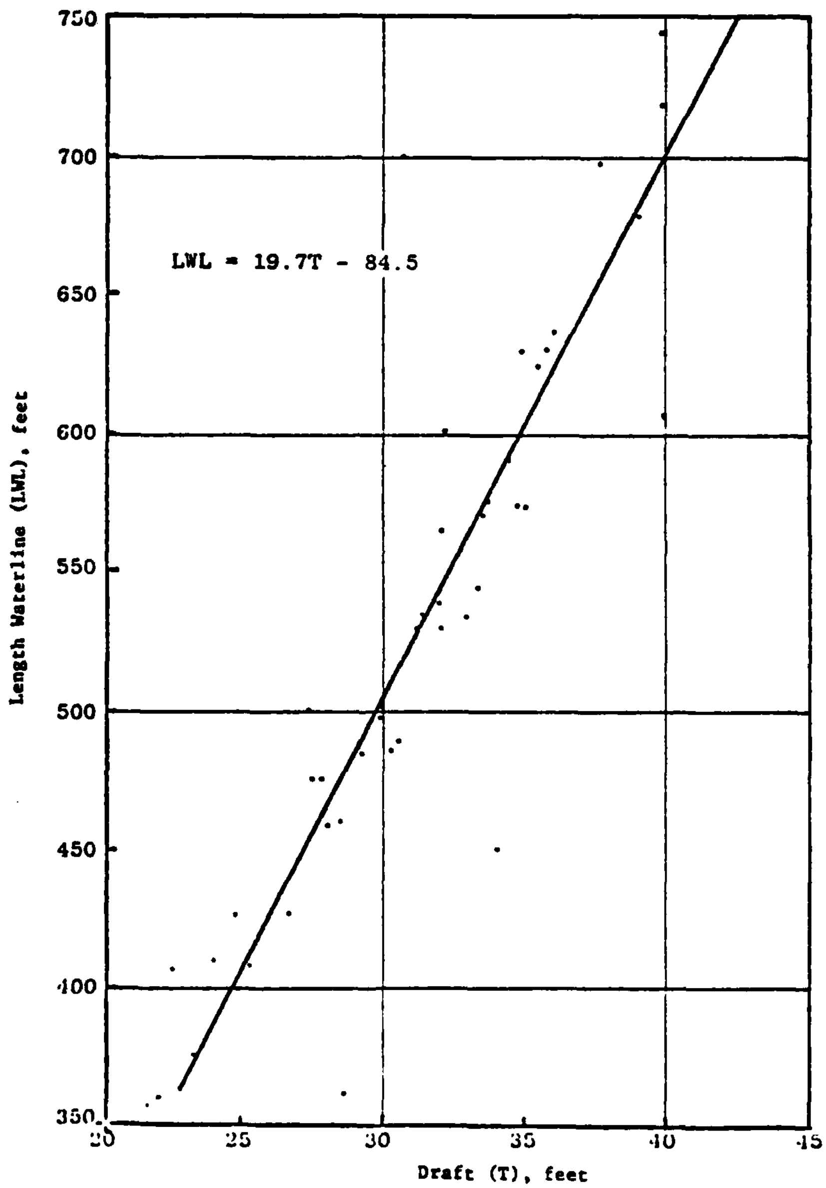

Figure A-1. Tankers - Full Load Draft vs. Length Waterline

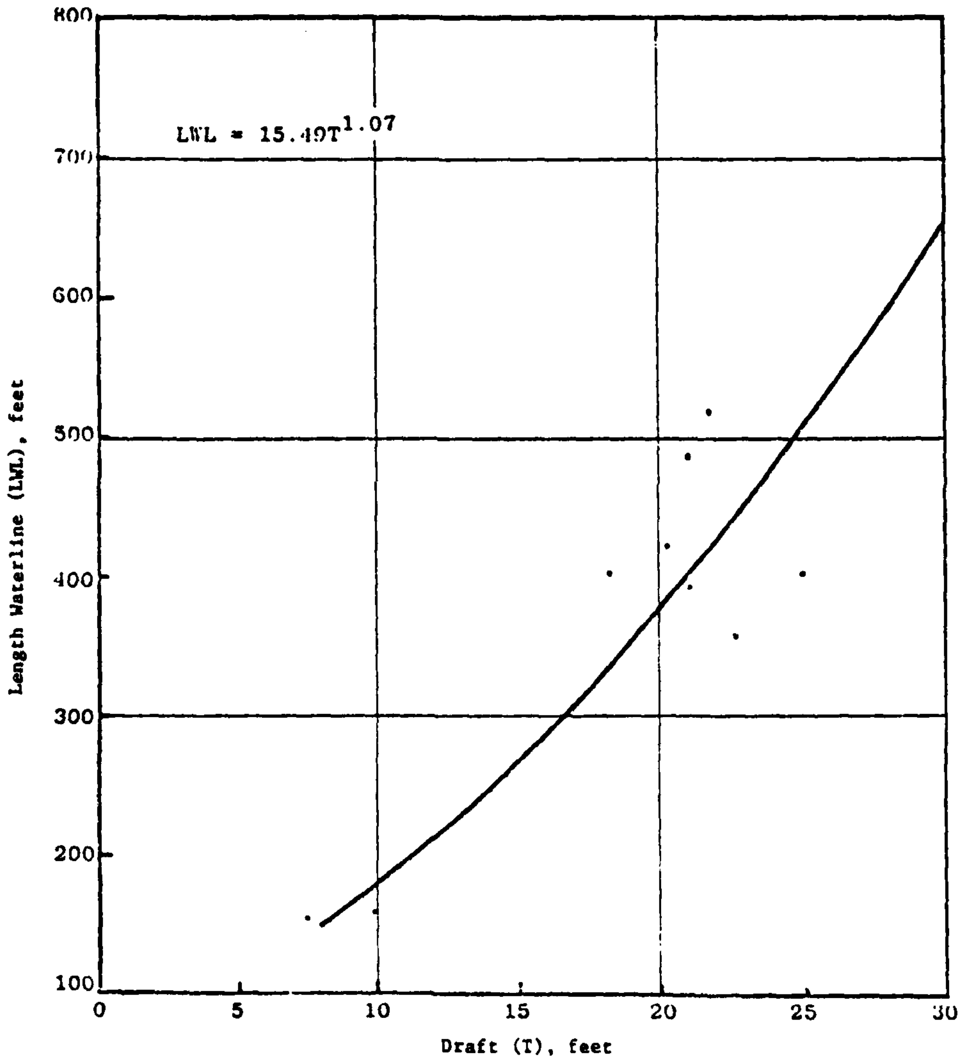

Figure A-2. Passenger Vessel - Full Load Draft vs. Length Waterline

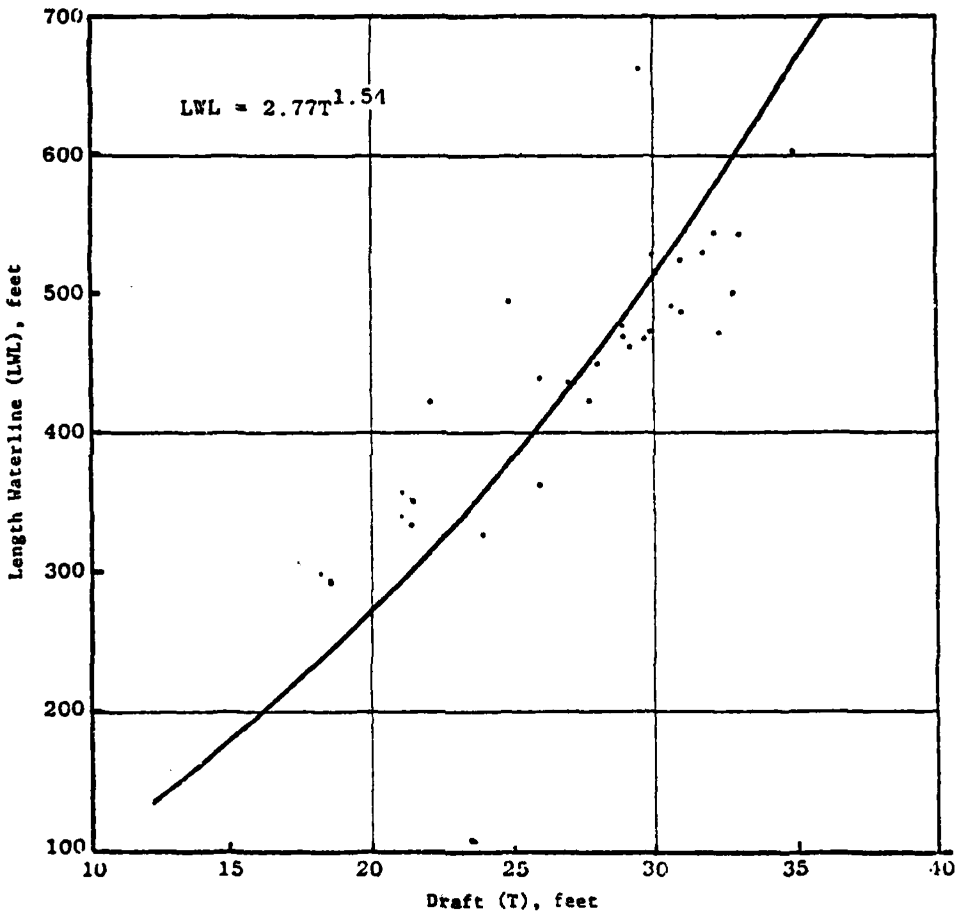

Figure A-3. General Cargo - Full Load Draft vs. Length Waterline

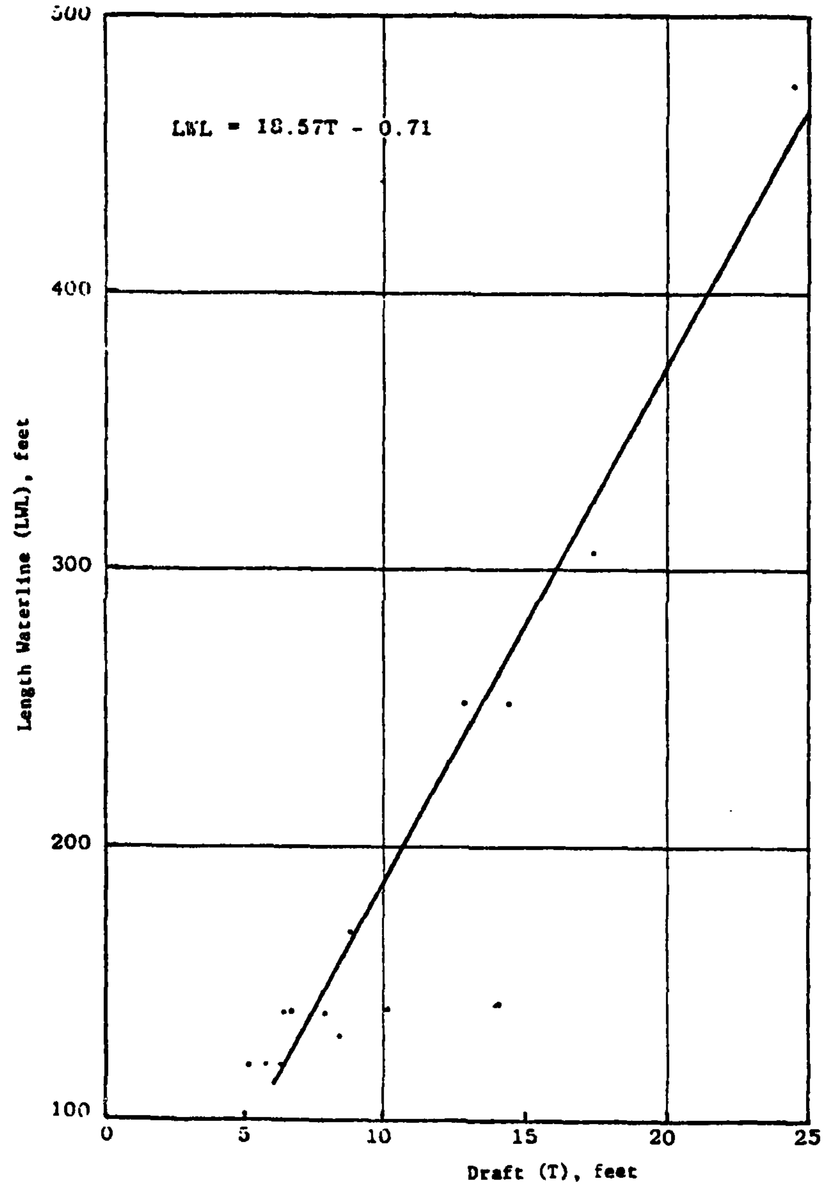

Figure A-4. Ocean Deck Barge - Full Load Draft vs. Length Waterline

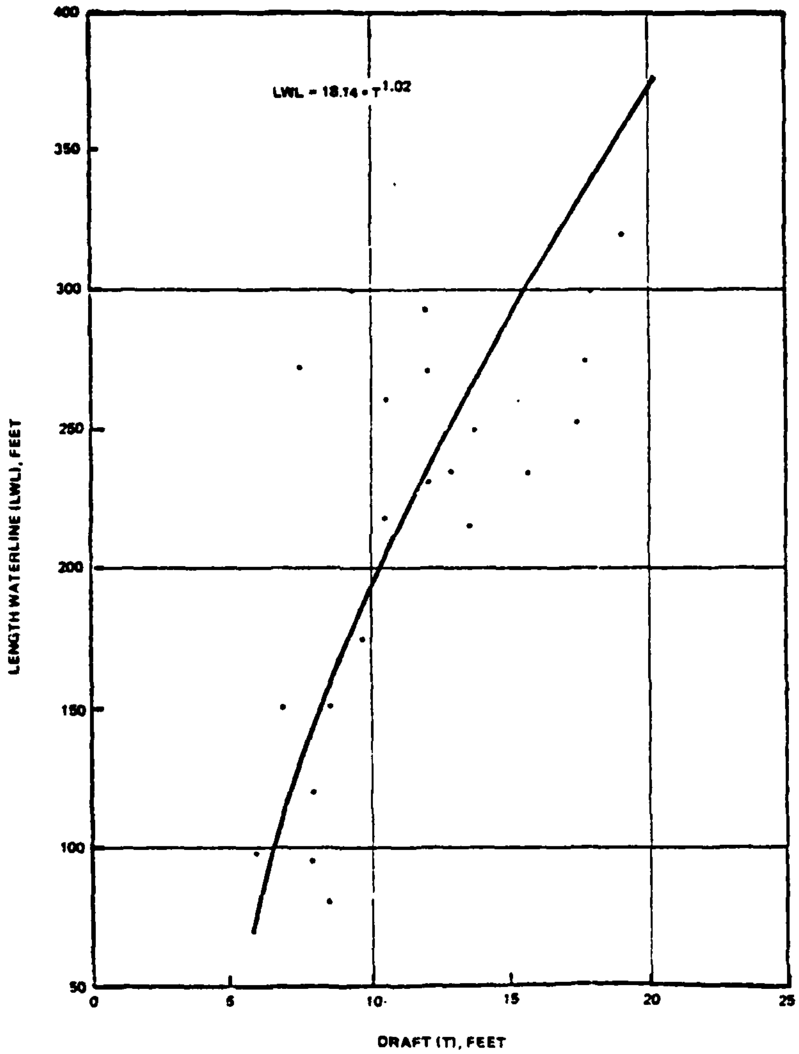

Figure A-5. Tank Barges – Full Load Draft vs. Length Waterline

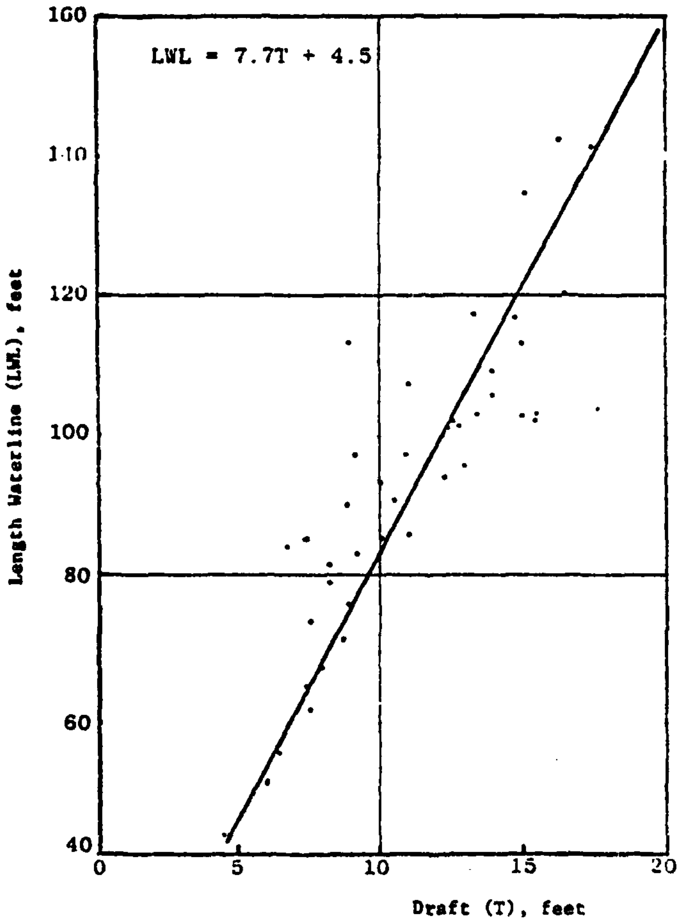

Figure A-6. Tugs - Full Load Draft vs. Length Waterline

APPENDIX B - PROJECT FIND

Table B-1 lists the collision attributes used by Project Find in sorting, evaluating, and analyzing statistically the casualty data recorded on computer tapes. Table B-2 illustrates the information available for each vessel casualty. The example in Table B-2 is case number 0117 from the fiscal year 1976 Vessel Casualty Records. Table B-2 also defines the seven Coast Guard attributes which were converted to numeric attributes to allow statistical evaluation (gross tonnage, length, etc.).

To demonstrate the versatility, flexibility and usefulness of Project Find, Table B-3 has been included. Table B-3 lists histograms for specific attributes for all the collisions in the fiscal year 1976 data base. The first column represents the value or definition for a particular attribute as defined in Reference 1. For example, under the attribute "month," the value 01 represents January, 02 represents February, etc.

Such analyses are available for individual ports, general areas such as the Pacific Coast in which this research is directed, ship-types, and ship sizes.

TABLE B-1. COLLISION ATTRIBUTES USED WITH PROJECT FIND

Coast Guard inspected
Type of vessel
Propulsion type
Person in charge of vessel maneuvers
Date
Special information (e.g., pollution)
Time of day
Vessel involvement (primary, secondary, etc.)
Gross tonnage
Length
Hull materials
Age of vessel
Location
Nature of casualty
Primary cause
Area of causal connection
Additional contributory factors
Weather
Visibility
Wind
Sea conditions
Personnel killed or injured
Estimated vessel, cargo and property losses
Vessel lost
Vessel nationality

TABLE B-2. EXAMPLE OF VESSEL INVOLVED IN COLLISION

Column	Value	Attribute	Meaning
1-5	00101	Find Number	One of the modifications incorporated to adapt the Coast Guard casualty data base on Project Find. The Find Number provides a unique identifier to each entity (or line).
6	Blank	None	
7	6	Fiscal Year of Casualty	Identifies the fiscal year in which the casualty occurred. (1976)
8-11	0117	Case Number	Identifies Coast Guard serialization of casualties. All ships involved in the same collision are listed under the same case number.
12-17	Greek	Official Name	Documented vessels of the United States report their official number. Foreign vessels report the country of registry, as in this case for Greek registry.
18	2	Coast Guard Inspected.	The value indicates that the vessel was not inspected by the Coast Guard.
19-20	25	Type of Vessel	Foreign freight vessel.
21	2	Propulsion	Diesel engine.
22	9	Person in Charge	Foreign Master
23-24	01	Month of Casualty	January
25-26	BE	Marine Inspection Office	New Orleans
27	6	Month Investigation Completed	June
28	5	Year of Casualty	1975
29-30	12	Time of Day	One of the string attributes of Coast Guard database converted to numeric attribute. The "day" code was converted to noon or 1200 hours.
31	3	Type of Investigative Report	Letter of Transmittal
32	1	Vessel Responsibility.	Primary responsibility for collision.

TABLE B-2 (Continued)

Column	Value	Attribute	Meaning
33-37	7500	Gross Tonnage (Tons)	String attribute of Coast Guard. Data base converted to numeric attribute. The ship was coded as "over 5000 to 10,000" tons and converted to 7500 tons.
38-40	450	Length (feet)	String attribute converted to numeric attribute. The ship was coded as "400 to less than 500" feet and converted to 450 feet.
40	1	Hull Material	Steel
42-45	17.5	Age of Vessel (Years)	String attribute converted to numeric attribute. For this case, the age of ship was coded as 15 to less than 20 years and converted to 17.5 yrs.
46-47	AX	Body of Water	Lower Mississippi River
48-49	04	Nature of Casualty	Collision with vessel anchored or moored.
50	J	Cause of Casualty	Storms or heavy weather
51	B	Factor	Gale Force Winds
52-54	039	Causal Connection	Weather
55-57	409	Additional Contributory Factors	Internal damage to ship.
58	5	Weather	Rain
59-61	.39	Visibility (miles)	String attribute converted to numeric. For this case, visibility was coded at 1/4 to less than 1/2 mile and converted to 0.39 mile.
62-65	60.5	Wind Speed (knots)	String attribute converted to numeric. The wind speed was coded as "55-65 knots" and converted to 60.5 knots.
66-68	090	Specific location of casualty	Indicates mile post reading on Mississippi River.
69-70	30	Sea Conditions (sea/swell in ft)	String attribute converted to numeric. The sea conditions were coded as "21-40 feet or heavy chop/very rough" and converted to 30 feet.

Table B-2 (Continued)

Column	Value	Attribute	Meaning
71-72	9R	Type of vessel	Bulk Carrier
73-74	00	Crew killed	None
75-76	00	Passengers killed	None
77-78	00	Longshoreman Killed	None
79-80	00	Others Killed	None
81-82	00	Crew Injured	None
83-84	00	Passengers Injured	None
85-86	00	Longshoreman Injured	None
87-88	00	Others Injured	None
89-92	0012	Damage to vessel	$12,000
93-96	0000	Damage to Cargo	None
97-100	0000	Damage to other Property	None
101	2	Vessel Lost ?	No
102	1	Special Indicator	Light oil pollution

Table B-3. Example of Computer Analysis For All Vessel Collisions (Fiscal Year 1976 Data Base)

```
FSTAT? HIS MONTH

HISTOGRAM FOR MONTH  (Each * is 10 Occurrences)

01 336 **********************************
02 266 ***************************
03 357 ************************************
04 382 ***************************************
05 366 *************************************
06 370 *************************************
07 470 ***********************************************
08 546 *******************************************************
09 338 **********************************
10 276 ****************************
11 274 ****************************
12 277 ****************************
36 1  *
DONE

FSTAT? HIS INSPECT

HISTOGRAM FOR INSPECT  (Each * is 51 Occurrences)

1 1215 ************************
2 3040 ************************************************************
DONE
```

```
FSTAT? HIS VESLTYPE

HISTOGRAM FOR VESLTYPE  (EACH * IS 24 OCCURRENCES)

01 15 *
02 224 **********
03 791 *********************************
04 48 **
05 60 ***
06 5  *
07 26 **
08 405 *****************
09 1379 **********************************************************
10 16 *
11 26 **
12 60 ***
13 17 *
14 2  *
15 2  *
17 109 *****
18 570 ************************
19 2  *
21 2  *
22 18 *
23 175 ********
24 5  *
25 160 *******
26 64 ***
27 39 **
28 1  *
29 23 *
DONE

FSTAT? HIS PERSRESP

HISTOGRAM FOR PERSRESP  (EACH * IS 26 OCCURRENCES)

0 1461 *********************************************************
1 293 ************
2 100 ****
3 11 *
4 5  *
5 1512 ***********************************************************
7 6  *
8 561 **********************
9 295 ************
A 2  *
DONE
```

```
FSTAT? HIS TOD

HISTOGRAM FOR TOD  (EACH * IS 47 OCCURRENCES)

 12             2129 **********************************************
 13             0
 14             0
 15             0
 16             0
 17             0
 18             272 ******
 19             0
 20             0
 21             0
 22             0
 23             0
 24             1819 ***************************************
DONE

FSTAT? HIS COLLTYPE

HISTOGRAM FOR COLLTYPE  (EACH * IS 21 OCCURRENCES)

01 487 ************************
02 77 ****
03 156 ********
04 451 **********************
05 115 ******
06 54 ***
07 522 *************************
08 169 *********
09 1204 **********************************************************
10 12 *
11 137 *******
12 54 ***
21 823 ****************************************
DONE

FSTAT? HIS WATERS

HISTOGRAM FOR WATERS  (EACH * IS 14 OCCURRENCES)

01 788 *********************************************************
02 574 *****************************************
03 390 ****************************
05 155 ************
06 111 ********
07 136 **********
09 3  *
11 11 *
12 162 ************
13 138 **********
AC 9  *
AF 2  *
AG 7  *
AJ 2  *
AL 12 *
AM 4  *
AN 3  *
AP 9  *                                                      ? CANCEL

CANCELLED
```

```
DONE

FSTAT? HIS PR1

HISTOGRAM FOR PR1  (EACH * IS 33 OCCURRENCES)

A 72 ***
B 25 *
C 96 ***
D 913 ****************************
E 6  *
F 262 ********
H 17 *
I 17 *
J 78 ***
K 81 ***
L 7  *
M 32 *
N 104 ****
O 133 *****
P 6  *
Q 233 ********
R 3  *
S 1  *
T 11 *
V 87 ***
W 1921 ***********************************************************
X 1  *
Y 122 ****
Z 25 *
DONE

FSTAT? HIS WEATHER

HISTOGRAM FOR WEATHER  (EACH * IS 40 OCCURRENCES)

1 2357 ***********************************************************
2 629 ****************
3 556 **************
4 276 *******
5 166 *****
6 29 *
7 119 ***
DONE

FSTAT? HIS LOST

HISTOGRAM FOR LOST  (EACH * IS 70 OCCURRENCES)

1 106 **
2 4155 ************************************************************
DONE
```

```
HISTOGRAM FOR PKILLED  (EACH * IS 93 OCCURRENCES)

 0              4258 **********************************************
 1              0
 2              1  *
 3              1  *
DONE

FSTAT? HIS CKILLED

HISTOGRAM FOR CKILLED  (EACH * IS 93 OCCURRENCES)

 0              4245 **********************************************
 1              9  *
 2              2  *
 3              2  *
 4              0
 5              1  *
 6              0
 7              1  *
DONE

FSTAT? HIS OKILLED

HISTOGRAM FOR OKILLED  (EACH * IS 93 OCCURRENCES)

 0              4259 **********************************************
DONE

FSTAT? HIS WKILLED

HISTOGRAM FOR WKILLED  (EACH * IS 93 OCCURRENCES)

 0              4260 **********************************************

HISTOGRAM FOR SPECIAL1  (EACH * IS 16 OCCURRENCES)

0 423 ***************************
1 202 *************
2 213 **************
3 247 ****************
4 373 ************************
5 300 *******************
6 502 ********************************
7 305 ********************
8 337 **********************
9 906 *********************************************************
A 285 ******************
B 163 ***********
0 5  *
DONE

FSTAT? HIS SPECIAL2

HISTOGRAM FOR SPECIAL2  (EACH * IS 57 OCCURRENCES)

0 3404 ************************************************************
1 44 *
2 62 **
3 10 *
6 12 *
8 728 *************
9 1  *
DONE
```

D-A083 567 CALIFORNIA UNIV LOS ANGELES SCHOOL OF ENGINEERING A--ETC F/G 13/10
A METHODOLOGY FOR ASSESSING ALTERNATIVES TO REDUCE SHIP COLLISI--ETC(U)
MAY 79 R R MORGAN, R R O'NEILL DOT-CG-83886-1B
UNCLASSIFIED UCLA-ENG-7939 USCG-M-5-79 NL

3 OF 3

END
DATE
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5-80
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```
FSTAT? STA DOLTOT

VARIABLE DOLTOT
===============

 80 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 11000   MINIMUM VALUE: 0   RANGE: 11000
SUM: 120085   SUM OF SQUARES: 3.52025 E+8   MEAN: 28.7216
MEDIAN VALUE: 2   VARIANCE: 83391.4   STD. DEV.: 288.776
STD. ERROR OF MEAN: 4.46602   COEFF. OF VARIANCE: 10.0543
DONE

FSTAT? STA LOSSCRGO

VARIABLE LOSSCRGO
=================

 8 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 9000   MINIMUM VALUE: 0   RANGE: 9000
SUM: 23801   SUM OF SQUARES: 1.44463 E+8   MEAN: 5.59628
MEDIAN VALUE: 0   VARIANCE: 33944.1   STD. DEV.: 184.239
STD. ERROR OF MEAN: 2.8251   COEFF. OF VARIANCE: 32.9217
DONE

FSTAT? STA LOSSVESL

VARIABLE LOSSVESL
=================

 76 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 9999   MINIMUM VALUE: 0   RANGE: 9999
SUM: 68807   SUM OF SQUARES: 119495185   MEAN: 16.4413
MEDIAN VALUE: 0   VARIANCE: 28289.7   STD. DEV.: 168.195
STD. ERROR OF MEAN: 2.59996   COEFF. OF VARIANCE: 10.23
DONE

FSTAT? STA LOSSOTHR

VARIABLE LOSSOTHR
=================

 9 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 5000   MINIMUM VALUE: 0   RANGE: 5000
SUM: 27572   SUM OF SQUARES: 39754766   MEAN: 6.48448
MEDIAN VALUE: 0   VARIANCE: 9074.57   STD. DEV.: 95.2605
STD. ERROR OF MEAN: 1.46087   COEFF. OF VARIANCE: 14.6905
DONE
```

```
FSTAT? STA LENGTH

VARIABLE LENGTH
===============

 187 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 750   MINIMUM VALUE: 33   RANGE: 717
SUM: 773953   SUM OF SQUARES: 2.77049 E+8   MEAN: 189.949
MEDIAN VALUE: 150   VARIANCE: 31931.4   STD. DEV.: 178.693
STD. ERROR OF MEAN: 2.79961   COEFF. OF VARIANCE: 0.940744
DONE

FSTAT? STA TONS

VARIABLE TONS
=============

 356 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 30000   MINIMUM VALUE: 7.5   RANGE: 29992.5
SUM: 13097504   SUM OF SQUARES: 2.57625 E+11   MEAN: 3354.03
MEDIAN VALUE: 400   VARIANCE: 54737623   STD. DEV.: 7378.49
STD. ERROR OF MEAN: 118.395   COEFF. OF VARIANCE: 2.20585
DONE

FSTAT? STA VISIBLTY

VARIABLE VISIBLTY
=================

 314 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 8   MINIMUM VALUE: 0.13   RANGE: 7.87
SUM: 26421.9   SUM OF SQUARES: 207523.   MEAN: 6.69418
MEDIAN VALUE: 8   VARIANCE: 7.76741   STD. DEV.: 2.78701
STD. ERROR OF MEAN: 4.43613 E-2   COEFF. OF VARIANCE: 0.416333
DONE

FSTAT? STA AGE

VARIABLE AGE
============

 290 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 55   MINIMUM VALUE: 2.5   RANGE: 52.5
SUM: 56737.5   SUM OF SQUARES: 1.15968 E+6   MEAN: 14.3006
MEDIAN VALUE: 7.5   VARIANCE: 163.121   STD. DEV.: 12.7719
STD. ERROR OF MEAN: 0.202677   COEFF. OF VARIANCE: 0.893103
DONE
```

FSTAT? STA SEA

VARIABLE SEA
============

2073 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 55   MINIMUM VALUE: 1   RANGE: 54
SUM: 16214   SUM OF SQUARES: 374000   MEAN: 7.41042
MEDIAN VALUE: 1   VARIANCE: 116.071   STD. DEV.: 10.7736
STD. ERROR OF MEAN: 0.230324   COEFF. OF VARIANCE: 1.45385
DONE

FSTAT? STA WIND

VARIABLE WIND
=============

1210 ENTITIES EXCLUDED FROM A TOTAL OF 4261

MAXIMUM VALUE: 75   MINIMUM VALUE: 0.5   RANGE: 74.5
SUM: 37772.5   SUM OF SQUARES: 923765.   MEAN: 12.3804
MEDIAN VALUE: 7   VARIANCE: 149.55   STD. DEV.: 12.2291
STD. ERROR OF MEAN: 0.221397   COEFF. OF VARIANCE: 0.987779
DONE

FIND NUM	CAS ENO	WAT ERS	LOCA TICN	COLL TYPE	VESL TYPE	LEN GTH	TONS	AGE	DOL TOT
00001	60001	07	X26	01	08	083	200.0	7.50	0
00002	60001	07	X26	01	23	033	--	45.0	1
00003	60006	WT	030	21	29	250	3000.	17.5	1
00004	60006	WT	030	21	09	083	200.0	35.0	1
00005	60008	07	X41	21	08	083	200.0	25.0	425
00006	60011	01	033	21	17	083	42.00	25.0	1
00007	60012	WS	002	04	09	150	750.0	2.50	0
00008	60012	WS	002	04	03	150	750.0	2.50	2
00009	60012	WS	002	04	03	150	750.0	12.5	0
00010	60018	07	X56	21	10	550	12500	12.5	20
00011	60019	03	818	08	08	033	7.500	45.0	16
00012	60020	03	318	21	08	033	7.500	45.0	2
00013	60022	WJ	162	09	09	150	--	25.0	0
00014	60022	WJ	162	09	18	250	3000.	17.5	15
00015	60024	WS	195	09	09	150	400.0	25.0	0
00016	60024	WS	185	09	29	250	12500	25.0	2

? CANCEK

*PRI: PRESS RETURN FOR NEXT PAGE, OR TYPE 'CANCEL'? CANCEL

APPENDIX C. FY'76 VESSEL CASUALTY RECORDS

Appendix C lists the ship collisions from the fiscal year 1976 Vessel Casualty Records occurring in the Pacific Coast ports analyzed. Appendix C also describes the analysis used to arrive at the collision statistics used to derive and validate the Collision Prediction Model. Vessel casualties omitted from consideration were fishing and naval vessel collisions and those occurring outside a five nautical mile radius of the port entrance.

The impact of eliminating fishing and naval vessels is discussed in Section IV. A criterion of a five nautical mile radius from the port entrance was imposed in order to be consistent with the scope of this research. A five nautical mile criterion is not considered restrictive since the great majority of collisions occur in or around ports.

PUGET SOUND (FY'76 VESSEL CASUALTY RECORDS)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Tacoma	01273	61343	83	85	Tug	Yes	
	01274	61343	550	592	Foreign Cargo	Yes	
	01275	61343	83	74	Tug	Yes	
	01358	61432	450	474	Foreign Cargo	Yes	
	01359	61432	83	74	Tug	Yes	
	01381	61460	250	808	Foreign Cargo	Yes	Length in meters incorrectly coded as feet.
	01382	61460	83	85	Tug	Yes	
	01383	61460	83	96	Tug	Yes	
	01968	62090	650	605	Cargo	Yes	
	02228	62328	150	544	Foreign Cargo	Yes	Length in meters incorrectly coded as feet.
	02229	62328	83	85	Tug	Yes	
	02230	62328	83	74	Tug	Yes	
	03700	63679	450	472	Foreign Cargo	Yes	
	03705	63686	83	–	Tug	Yes	
	03706	63686	450	472	Foreign Cargo	No	Duplicate entry in computer tape. Identical to 03700.
Port Angeles	00106	60120	83	90	Tug	Yes	
	00107	60120	250	260	Barge	Yes	
	00771	60770	33	45	Motor Craft	Yes	
	00802	60791	450	455	Cargo	Yes	Ex USNS MIFFLIN under tow.
	00803	60791	150	112	Tug	Yes	
	00804	60791	33	49	Fishing	No	Fishing vessels not counted.

PUGET SOUND (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Port Angeles (continued)	00930	60933	33	–	Fishing	No	Fishing vessels not counted.
	00931	60933	33	–	Fishing	No	Fishing vessels not counted.
Port Townsend	00285	60279	33	39	Motor Craft	Yes	
	00303	60297	250	260	Cargo Barge	Yes	
	00304	60297	83	72	Tug	Yes	
	00651	60666	150	464	Cargo	No	Collision occurred in Port Gardenier Bay.
	00652	60666	150	108	Tug	No	Collision occurred in Port Gardenier Bay.
Everett	03692	63669	33	–	Fishing	No	Fishing vessels not counted.
	03726	63712	33	–	Fishing	No	Fishing vessels not counted.
Olympia	None						
Bellingham	None						
Seattle	00355	60366	33	60	Tug	Yes	
	00356	60366	33	55	Motor Yacht	Yes	
	00407	60415	83	89	Passenger Jetfoil	Yes	
	01216	61273	750	946	Container	Yes	
	01463	61568	250	240	Barge	No	Collision occurred in Desolation Sound, British Columbia.
	01464	61568	350	309	Dredge	No	
	01465	61568	150	150	Tug	No	
	01765	61874	750	790	Cargo	No	Collision occurred off Neah Bay, Straits of Juan de Fuca.
	01766	61874	150	123	Tug	No	

PUGET SOUND (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Seattle (continued)	01861	61976	83	72	Tug	No	Collision occurred in Rosario Strait.
	01862	61976	150	173	Cargo	No	
	01969	62091	33	33	Fishing	No	Fishing vessels not counted
	01970	62091	150	160	Tug	Yes	
	01971	62091	150	106	Tug	Yes	
	02177	62293	83	93	Tug	Yes	
	02178	62293	550	571	Foreign Cargo	Yes	
	02957	62989	350	310	Ferry	Yes	
	03126	63165	33	61	Tug	No	Collision occurred off West Point, Washington.
	03127	63165	83	100	Barge	No	
	03128	63167	83	90	Tug	Yes	
	03129	63167	550	564	Foreign Cargo	Yes	
	03130	63167	150	103	Tug	Yes	
	03131	63167	83	70	Tug	Yes	
	03438	63424	83	72	Tug	Yes	
	03439	63424	450	466	Foreign Cargo	Yes	
	03440	63424	150	115	Tug	Yes	
	03546	63518	83	96	Tug	Yes	
	03547	63518	350	317	Barge	Yes	
	03688	63667	33	-	Fishing	No	Fishing vessels not counted.
	03689	63667	33	-	Fishing	No	Fishing vessels not counted.
	03690	63668	83	96	Tug	No	Duplicate entries to Case No. 63518.
	03691	63668	350	317	Barge	No	
	03693	63670	83	99	Tug	No	

PUGET SOUND (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Seattle (continued)	03694	63670	150	106	Fishing	No	Collision occurred in Main Pass, British Columbia
	03695	63670	350	314	Barge	No	
	03696	63672	33	–	Fishing	No	Fishing vessels not counted.
	03697	63672	33	–	Fishing	No	Fishing vessels not counted.
	03722	63711	83	80	Tug	Yes	
	03723	63711	150	110	Tug	Yes	
	03724	63711	83	72	Tug	Yes	
	03725	63711	550	580	Foreign Cargo	Yes	
Anacortes	00060	60081	250	260	Barge	Yes	
	00061	60081	83	90	Tug	Yes	
	00353	60365	33	42	Motor Yacht	Yes	
	00354	60365	33	33	Passenger	Yes	

SOUTHERN CALIFORNIA (FY'76 VESSEL CASUALTY RECORDS)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
San Diego	00233	60240	33	50	Fishing	No	Fishing vessels not counted.
	00234	60241	33	–	Passenger	Yes	
	00235	60241	–	–	Naval Barge	No	Naval vessels not counted.
	00236	60241	–	–	Naval Vessel	No	Naval vessels not counted.
	01442	61542	150	144	Motor Craft	No	Collision occurred 9 miles north of Santa Catalina Island
	01443	61542	550	509	Foreign Freight	No	
	01549	61643	–	–	Naval Vessel	No	Naval vessels not counted.
	01550	61643	150	159	Motor Craft	Yes	
	01923	62046	33	44	Oil Catamaran	Yes	
	02755	62761	150	165	Fishing	No	Fishing vessles not counted.
	02836	62855	550	560	Cargo	Yes	
	02876	62906	33	44	Power Yacht	No	Collision occurred off South Coronado Island, Mexico.
	03321	63312	–	–	Motor Craft	Yes	Assumed length <400 feet
	03322	63312	–	–	Barge	No	This barge not in collision.
	03323	63312	–	–	Barge	No	This barge not in collision.
	03324	63312	–	–	Barge	Yes	Last barge in tow was involved in collision. Assumed less than 400 feet.
	03325	63312	–	–	Tug	No	Only barge collided, not tug.

SOUTHERN CALIFORNIA (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Long Beach	00443	60448	150	179	Barge	No	Collision occurred 3 miles off Pt. Vincente Light.
	00444	60448	150	115	Tug	No	
	00445	60448	33	36	Pleasure Craft	No	
	01660	61760	650	659	Container Ship	Yes	
	02826	62844	–	–	Barge	Yes	
	02827	62844	750	486	Foreign Cargo	Yes	Length incorrectly coded.
Los Angeles/ San Pedro/ Wilmington	00812	60804	550	523	Tanker	Yes	
	01030	61071	33	51	Tug or Towboat	Yes	
	01269	61341	750	857	Foreign Tanker	Yes	
	01419	61517	33	–	Motor Craft	Yes	
	01420	61517	33	39	Motor	Yes	
	01421	61517	33	–	Motor Craft	Yes	
	01506	61599	650	672	Tanker	Yes	
	01507	61599	–	–	Motor Craft	Yes	Assumed length <400 feet.
	01575	61663	33	35	Fishing	No	Fishing vessels not counted.
	01576	61663	650	701	Cargo	Yes	Counted in ≥700 feet category.
	01776	61889	650	634	Tanker	Yes	
	01777	61889	150	195	Tank Barge	Yes	
	01778	61889	83	92	Tug	Yes	
	01991	62105	83	81	Tug	Yes	
	01992	62105	650	672	Tanker	Yes	
	02694	62714	450	497	Foreign Cargo	Yes	
	02695	62714	83	94	Tug or Towboat	Yes	
	02696	62714	33	45	Passenger	Yes	

SAN FRANCISCO BAY (FY'76 VESSEL CASUALTY RECORDS)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Redwood City	00573	60572	33	37	Auxiliary Sloop	Yes	
	00574	60572	-	-	Unmotored Sailboat	No	Sailboat not counted since traffic not included in reported transits.
Richmond	01206	61261	550	560	Foreign Tanker	Yes	
	02148	62253	650	672	Tanker	Yes	
	02709	62722	650	634	Tanker	Yes	
Stockton	00088	60104	350	312	Cargo Barge	Yes	
	00089	60104	150	106	Tug	Yes	
	00999	61040	150	656	Foreign Freight	Yes	Error in transposing data to VCR. Length in meters incorrectly entered as feet.
San Francisco	00092	60109	33	64	Tug or Towboat	No	Collision occurred on Sacramento River near Bay Beacons no. 24 and 26. Not in San Francisco harbor. Incorrectly coded.
	00093	60109	-	-	Cargo Barge	No	
	00274	60273	33	50	Fishing	No	Collision occurred in Diablo Cove.
	00449	60460	33	-	Sailboat	No	Sailboat not counted since traffic not included in reported transits.
	01241	61306	33	36	Power Cruiser	Yes	
	01920	62040	33	64	Tug or Towboat	No	Collision occurred on Sacramento River.
	02427	62509	550	523	Tanker	Yes	
	02428	62509	83	93	Tug	Yes	

SAN FRANCISCO BAY (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
	00195	60206	650	669	Foreign Tanker	No	Collision occurred at Benecia Martinez Bridge.
	00998	61039	750	820	Cargo	Yes	
	02843	62872	550	522	Cargo	Yes	Coded as SFRAN Bay. Grounding occurred at basin entrance.
Oakland/ Alameda	01710	61811	250	260	Tank Barge	Yes	
	01711	61812	650	662	Motor Craft	Yes	
	02168	62273	33	54	Pleasure Craft	Yes	
	02169	62273	-	-	Sailboat	No	Sailboat not counted since traffic not included.

HAWAII (FY'76 VESSEL CASUALTY RECORDS)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Kahului	00563	60556	83	77	Tug	Yes	
	00564	60556	150	178	Barge	Yes	
	02828	62846	450	430	Barge	Yes	
Honolulu	00900	60890	–	–	Fishing	No	Fishing vessels not counted.
	00899	60890	650	700	Cargo	Yes	Counted in ≥700 feet category.
	01247	61315	33	42	Tug	Yes	
	01248	61315	150	180	Barge	Yes	
	01249	61315	33	42	Motor Craft	Yes	
	01250	61315	33	45	Tug	Yes	
	00165	60179	250	258	Tank Barge	Yes	
	00166	60179	33	60	Tug	Yes	
	00818	60809	33	–	Motor Craft	Yes	
	00817	60809	150	117	Tug	Yes	
	01353	61420	83	74	Passenger	Yes	
	02193	62303	650	634	Tanker	Yes	
	02971	63014	750	720	Cargo	Yes	
Nawiliwili	00386	60393	650	663	Cargo	Yes	
	01352	61418	83	74	Passenger	Yes	
	02786	62792	650	641	Cargo	Yes	
Hilo	None						
Kawaihae	None						
Kanakaki	None						

ALASKA (FY'76 VESSEL CASUALTY RECORDS)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Wrangell	00634	60656	33	–	Fishing	No	Fishing vessels not counted.
	01296	61374	33	52	Fishing	No	Fishing vessels not counted.
	01297	61374	250	290	Tug	Yes	
	01579	61668	83	–	Fishing	No	Fishing vessels not counted.
Sitka	00690	60681	33	–	Fishing	No	Fishing vessels not counted.
	01138	61191	33	–	Fishing	No	Fishing vessels not counted.
	03681	63650	250	290	Barge	No	Collision occurred in Sergius Narrows.
	03682	63650	150	117	Tug	No	
Kodiak	00515	60513	33	–	Fishing	No	Fishing vessels not counted.
	00521	60517	83	–	Fishing	No	Fishing vessels not counted.
	00600	60596	83	–	Fishing	No	Fishing vessels not counted.
	01744	61841	33	–	Fishing	No	Fishing vessels not counted.
	02025	62133	33	45	Tug	No	Collision occured in Shelikof Strait.
	02080	62191	83	–	Fishing	No	Fishing vessels not counted.
	02767	62769	150	135	Tug	Yes	
	02766	62769	33	46	Barge	Yes	
	02765	62769	83	77	Fishing	No	Fishing vessels not counted.
	02856	62885	33	45	Fishing	No	Fishing vessels not counted.
	02991	63035	83	–	Fishing	No	Fishing vessels not counted.

ALASKA (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
	03392	63381	150	113	Fishing	No	Fishing vessel. Incorrectly coded as Tug.
	03649	63614	–	–	Fishing	No	Fishing vessels not counted.
	03650	63614	33	–	Fishing	No	Fishing vessels not counted.
	03685	63664	83	82	Fishing	No	Fishing vessels not counted.
	03686	63664	–	–	Ferry	Yes	Assumed <400 ft. category.
Skagaway	00033	60046	33	–	Fishing	No	Fishing vessels not counted.
	03683	63652	150	492	Foreign Passenger	Yes	Meters incorrectly coded as feet.
	03684	63655	–	571	Foreign Cargo	Yes	
	03795	63763	150	492	Foreign Passenger	No	Collision occurred in Glacier Bay with submerged object.
Valdez	00513	60511	350	400	Barge	Yes	Counted in 4<500 ft. category.
	01562	61652	150	116	Tug	Yes	
	02762	62766	33	–	Fishing	No	Fishing vessels not counted.
Seward	01033	61075	350	400	Barge	Yes	Included in 4<500 ft. category.
	01034	61075	150	142	Tug	Yes	
	01612	61718	83	–	Fishing	No	Fishing vessels not counted.
	04260	64219	350	400	Barge	No	Grounding occurred on Montague Island in Gulf of Alaska.
	04261	64219	150	115	Tug	No	

ALASKA (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Ketchikan	00273	60271	33	38	Fishing	No	Fishing vessels not counted.
	00393	60397	–	–	Motor Craft	Yes	Included in <400 ft category.
	00394	60397	83	80	Ferry	Yes	
	00514	60512	83	99	Passenger	Yes	
	01137	61190	33	–	Fishing	No	Fishing vessels not counted.
	01253	61325	150	200	Barge	No	Grounding occurred near Tolstoi Point, Prince of Wales.
	01479	61577	33	–	Fishing	No	Fishing vessels not counted.
	01547	61640	83	–	Fishing	No	Fishing vessels not counted.
	01548	61641	33	–	Fishing	No	Fishing vessels not counted.
	01661	61761	33	–	Fishing	No	Fishing vessels not counted.
	01814	61930	83	79	Barge	No	Grounding occurred in Moira Sound.
	03150	63190	33	–	Fishing	No	Fishing vessels not counted.
	03530	63503	33	–	Fishing	No	Fishing vessels not counted.
	03541	63512	33	–	Fishing	No	Fishing vessels not counted.
	03680	63647	83	94	Tug	Yes	
	04131	64084	250	–	Barge	Yes	
Anchorage	00400	60406	250	270	Passenger	Yes	
	00512	60510	750	744	Cargo	Yes	
	00516	60514	150	160	Tank Barge	No	Collision occurred 5 miles north of Point Lay Village.
	00517	60514	83	76	Tug	No	

ALASKA (FY'76 VESSEL CASUALTY RECORDS) (continued)

Location	Find No.	Case No.	Coded Length (ft)	Actual Length (ft)	Vessel Type	Collision Counted	Comment
Anchorage (continued)	00701	60695	150	106	Tug	Yes	
	00702	60695	250	275	Tank Barge	Yes	
	01002	61047	83	–	Fishing	No	Fishing vessels not counted.
	01036	61078	83	–	Fishing	No	Fishing vessels not counted.
	01251	61324	350	312	Barge	No	Collision occurred at Collier Pier, Nikiski Cook Inlet.
	01252	61324	150	135	Tug	No	
	01713	61815	83	55	Tug	No	Collision occurred out in Cook Inlet.
	01714	61815	250	250	Tank Barge	No	
	01742	61840	250	275	Tank Barge	Yes	
	01743	61840	83	95	Tug	Yes	
	01745	61842	83	–	Fishing	No	Fishing vessels not counted.
	01972	62092	150	155	Oil Explorer	No	Collision occurred at Nikiski.
	01989	62104	250	95	Tug	No	Collision occurred out in Cook Inlet.
	01990	62104	250	250	Tank Barge	No	
	02400	62439	450	497	Cargo	Yes	
	02401	62489	150	110	Barge	Yes	
	02402	62489	33	48	Tug	Yes	
	02905	62925	550	547	Tanker	No	Collision occurred in Norton Sound
	02906	62925	–	–	Foreign	No	
	02982	63025	150	114	Cargo	No	Collision occurred near Fire Island, Cook Inlet.
	02989	63034	150	200	Barge	No	Grounding occurred on Nushagak River.
	02990	63034	83	100	Tug	No	
	03384	63373	33	–	Fishing	No	Fishing vessels not counted.
	03534	63507	33	–	Fishing	No	Fishing vessels not counted.
	03536	63509	33	–	Fishing	No	Fishing vessels not counted.
	03542	63515	83	–	Fishing	No	Fishing vessels not counted.
	03544	63517	250	275	Tank Barge	No	Collision occurred at Nikiski.
	03545	63517	83	90	Tug	No	
	[illegible]	[illegible]	33	–	Fishing	No	Fishing vessels [illegible]

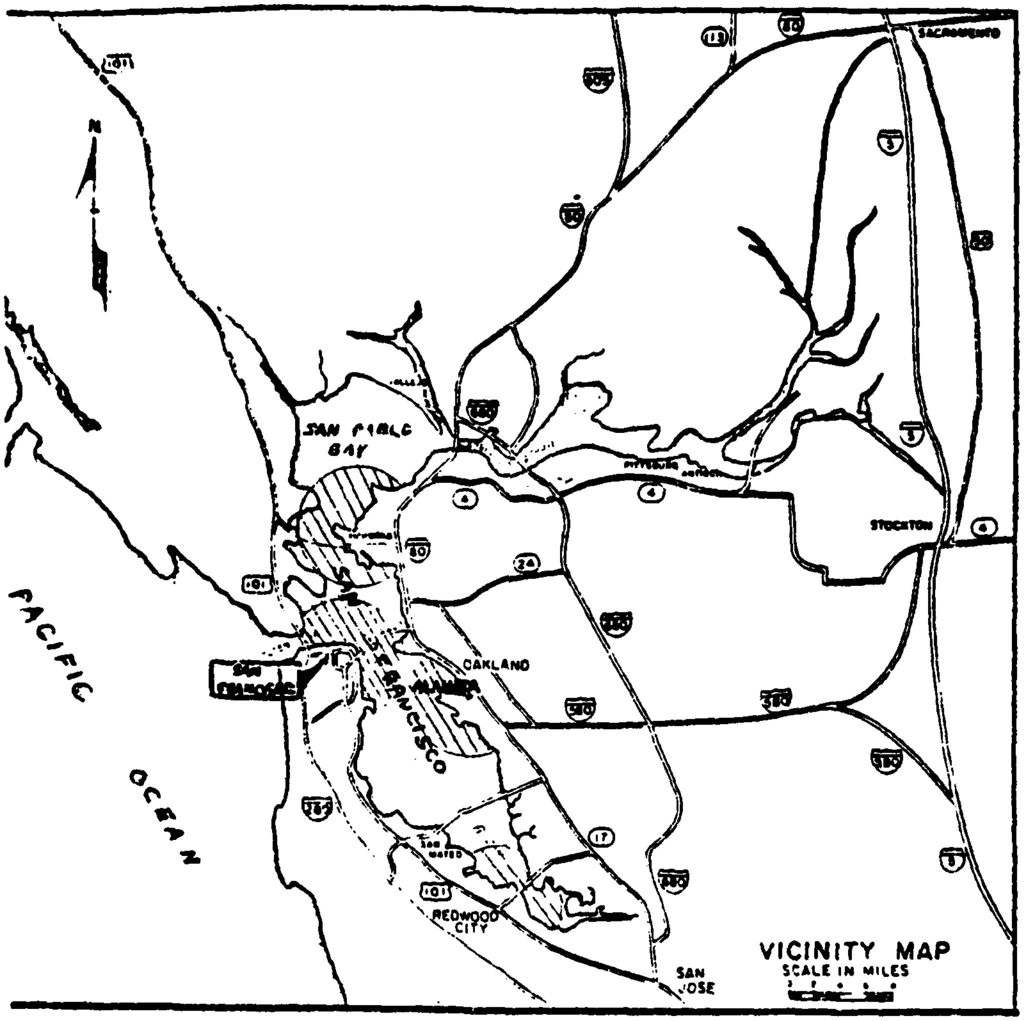

Figure C-1. San Francisco Bay Collision Boundaries

APPENDIX D

SHIP LENGTH AND THE SHIFTED EXPONENTIAL DISTRIBUTION

Probability distributions can be used in two ways: analysis of data on observed behavior and prediction of future behavior. By fitting a distribution to the data, data analysis can be simplified. When proven that physical phenomena can be represented by a certain type of distribution (or not proven that it cannot), the probability distribution can be used. In support of this research, being able to describe ship lengths entering and leaving ports by a probability distribution would be most helpful.

Fujii of Japan (Reference 14) points out that the distribution of ship sizes in Japanese sea lanes closely approximates the logarithmic Gaussian distribution. Evaluation of ship length data for American ports indicates that other distributions in addition to the logarithmic Gaussian (log normal) distribution can be used to approximate the distribution of ship lengths. One such probability distributions is the shifted exponential distribution. The shifted exponential distribution is easier to derive and use and thus is preferred over the logarithmic Gaussian distribution.

A review of ship length versus number of ships entering a typical port results in a histogram as shown in Figure D-1. To determine whether or not the shifted exponential distribution can be used to approximate the distribution of ship lengths entering ports, both graphic and statistical techniques are used.

Figure D-2 illustrates how the shifted exponential distribution can be expected to approximate the distribution of ship lengths.

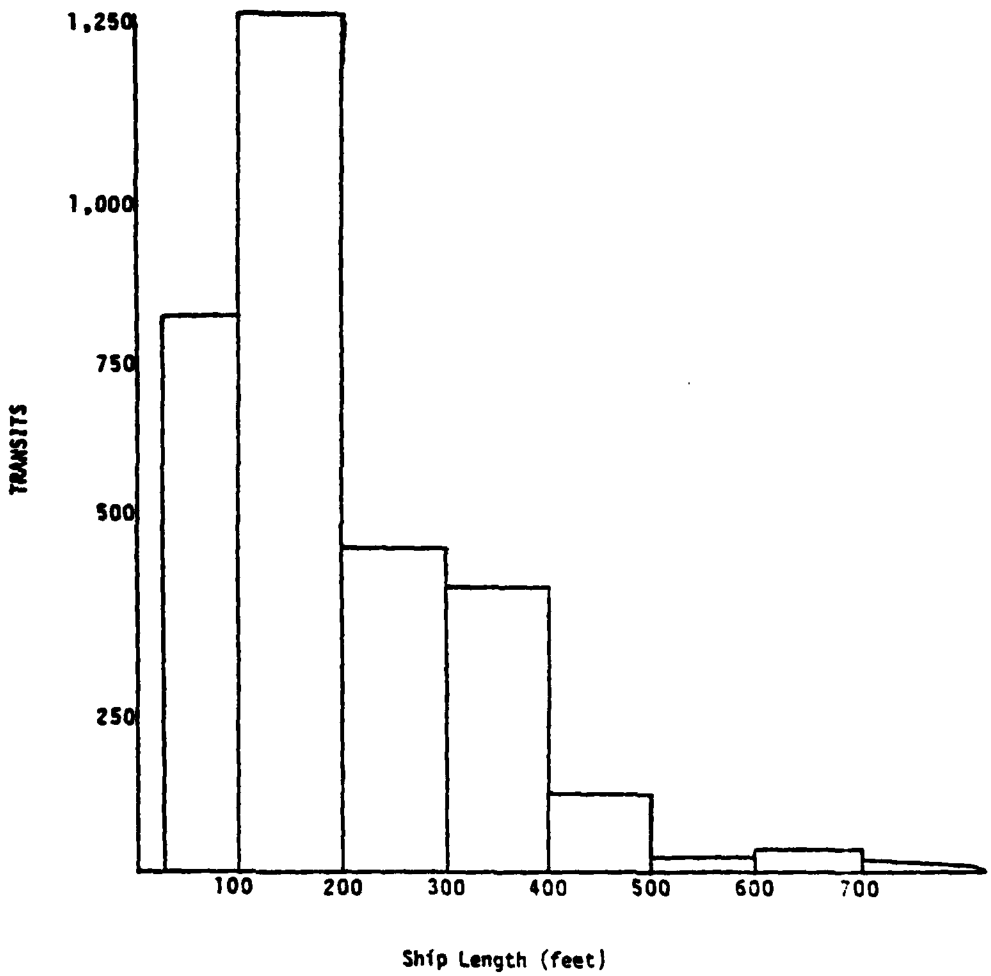

Figure D-1. Histogram of Transits for San Diego (1977)

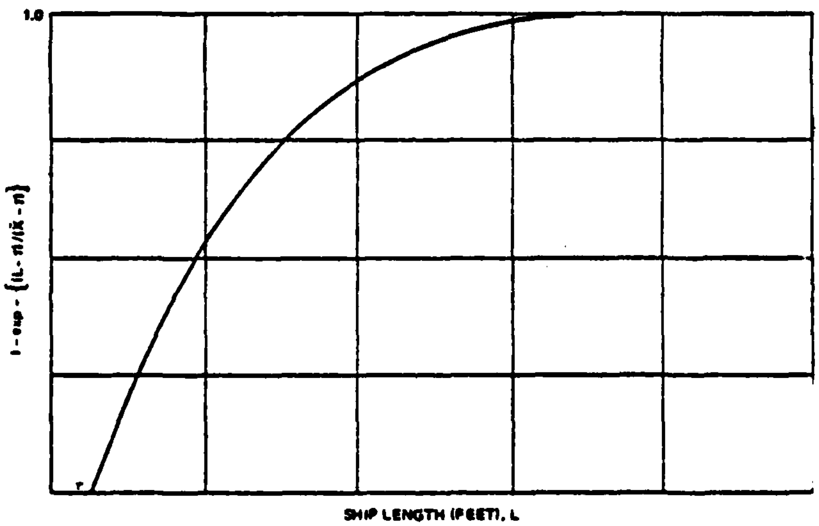

Figure D-2. Probability of Ship Length Less Than Length, L

Figure D-2 shows a zero probability for minimum size lengths and also shows an exponential increase in the cumulative probability of ship lengths. This obeys the physical laws of practicality in that a commercial vessel must have some minimum length to be of any value.

Figure D-3 is a plot of cumulative probability versus ship length for the ports of San Diego and Tacoma. These ports were selected since they represent two ports with widely differing amounts of traffic. If the distribution of ship length is exponential, the data should show up as a straight line. As the figure shows, the cumulative probability of ship size can be approximated by a straight line. Also shown is the effect of a minimum ship length and therefore the basis for the reasoning that the shifted exponential distribution is more appropriate than the exponential distribution.

Table D-1 shows a comparison of actual ship size transits and those predicted by the shifted exponential distribution for ship length intervals of approximately 100 feet for San Diego. The minimum ship length is assumed as 33 feet, based on a review of the 1976 and 1977 Pacific Coast casualty records.

In order to see if the exponential distribution is a reasonable approximation, the Kolmogorov-Smirnov (K&S) Goodness-of-Fit Test as modified by Reference 15 is applied. The largest value appearing in the last column of Table D-1 is 0.113. From Reference 15, for a sample size of 9 (8 degrees of freedom), the probability is greater than 80 percent that a number larger than 0.113 will be encountered. Since a probability of greater than 20 percent is generally considered

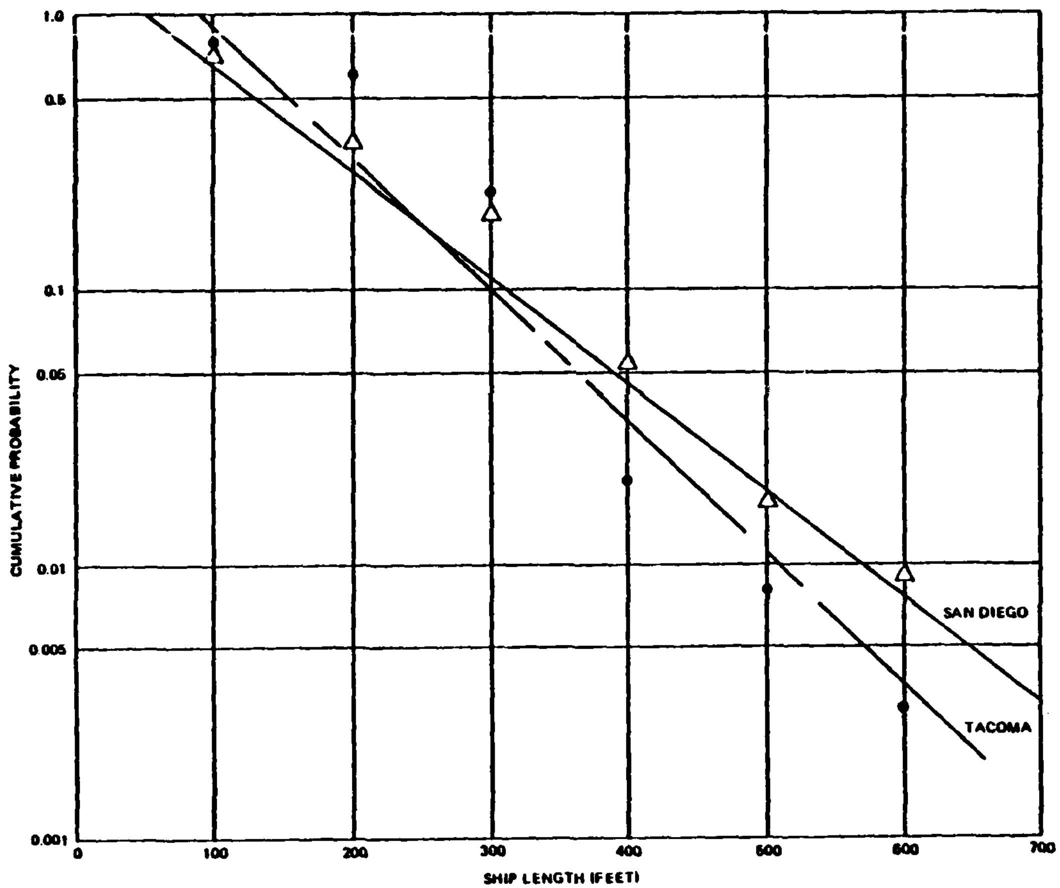

Figure D-3. Distribution of Ship Size for San Diego and Tacoma

TABLE D-1. SHIFTED EXPONENTIAL DISTRIBUTION AND SHIP SIZE FOR SAN DIEGO (1977)

Ship Length Feet, (X)	Number Of Ships	Cumulative Probability	Theoretical Cumulative $e^{-\left\{\frac{X-33}{\bar{X}-33}\right\}}$	Absolute Value Of Difference
> 33	3142	1.0	1.0	0
> 65	2918	0.929	0.816	0.113
> 100	2320	0.738	0.654	0.084
> 200	1068	0.340	0.347	0.007
> 300	588	0.187	0.184	0.003
> 400	172	0.055	0.098	0.043
> 500	52	0.017	0.052	0.035
> 600	28	0.009	0.028	0.019
> 700	2	0.001	0.015	0.014

The mean value ($\bar{X}$) for ship length is calculated from:

$$\bar{X} = \frac{(112)(50) + (299)(82.5) + (626)(150) + (240)(250) + (208)(350) + (60)(450) + (12)(550) + (13)(650) + (1)(750)}{1571}$$

$= 190.81$

and $\bar{X} - 33 = 190.81 - 33 = 157.81$

sufficient to show that a given distribution fits that data, the assumption of the shifted exponential distribution is valid.

A similar analysis for Tacoma is shown in Table D-2.

The largest value appearing in the last column of Table D-2 is 0.25. From Reference 15, for a sample size of 9 (8 degrees of freedom), the probability is greater than 80 percent that a number greater than 0.25 will be encountered. As with the previous example, the assumption that ship length can be approximated by the shifted exponential distribution is valid for Tacoma. Based upon the excellent results for these two ports, the assumption that ship length can be approximated by the shifted exponential distribution appears valid for a wide range of ports.

The importance of assigning a probability density function to ship length is that it assists in using the Collision Prediction Model. For example, by estimating the mean value for ship length, the percentage of ship lengths can be derived. In conjunction with an estimated total ship traffic, the number of ships in various length intervals can also be calculated. The number of ships in various length intervals is one of the inputs to the Collision Prediction Model.

TABLE D-2. SHIFTED EXPONENTIAL DISTRIBUTION AND SHIP SIZE FOR TACOMA (1977)

Ship Length feet, (X)	Number Of Ships	Cumulative Probability	Theoretical Cumulative $e^{-\left\{\frac{X-33}{\bar{X}-33}\right\}}$	Absolute Value of Difference
> 33	118,554	1.0	1.0	0.00
> 65	111,982	0.94	0.82	0.12
> 100	94,108	0.79	0.67	0.12
> 200	71,878	0.61	0.36	0.25
> 300	27,444	0.23	0.20	0.03
> 400	1,942	0.02	0.11	0.09
> 500	934	0.008	0.06	0.05
> 600	298	0.003	0.03	0.03
> 700	4	0.000	0.02	0.02

The mean value ($\bar{X}$) for ship length is calculated from:

$$\bar{X} = \frac{(1173)(50) + (8937)(82.4) + (11{,}115)(150) + (34{,}567)(250) + (401)(350) + (504)(450) + (318)(550) + (147)(650) + (2)(750)}{59{,}257}$$

$$= 198.17$$

and $\bar{X} - 33 = 198.17 - 33 = 165.17$

APPENDIX E. FY'77 VESSEL CASUALTY RECORDS

Appendix E lists the ship collisions from the fiscal year 1977 Vessel Casualty Records occurring in the Pacific Coast ports analyzed. Appendix E also describes the analysis used to arrive at the collision statistics used to derive and validate the Collision Prediction Model. Vessel casualties omitted from consideration were fishing and naval vessel collisions and those occurring outside a five nautical mile radius of the port entrance.

The impact of eliminating fishing and naval vessels is discussed in Section IV. A criterion of a five nautical mile radius from the port entrance was imposed in order to be consistent with the scope of this research. A five nautical mile criterion is not considered restrictive since the great majority of collisions occur in or around ports.

APPENDIX E - FY'77 VESSEL CASUALTY RECORDS

SOUTHERN CALIFORNIA (FY'77 VESSEL CASUALTY RECORDS)

Location	Case No.	Actual Length (feet)	Vessel Type	Collision Counted	Comment
San Diego	70297	88	Passenger	Yes	
	70297	52	Passenger	Yes	
	70437	223	Barge	Yes	
	70437	95	Tug	Yes	
	70437	-	Motorboat	Yes	
	70503	85	Passenger	Yes	
	70503	39	Fishing	No	Fishing vessels not counted.
	72535	69	Passenger	Yes	
	72541	62	Tow	Yes	
	72541	140	Barge	Yes	
	72541	93	Tow	Yes	
	72541	-	Navy Barge	No	Naval vessels not counted.
	72606	-	Fishing	No	Fishing vessels not counted.
	72606	-	Fishing	No	Fishing vessels not counted.
	72822	57	Passenger	Yes	
	72897	100	Navy Tug	No	Naval vessels not counted.
	72897	951	Tanker	Yes	
Long Beach	70092	571	Tanker	Yes	
	72299	119	Tug	Yes	
	72509	-	Motorboat	Yes	
	72509	-	Fishing	No	Fishing vessels not counted.
	72559	-	Fishing	No	Fishing vessels not counted.
	73064	-	Fishing	No	Fishing vessels not counted.
	73484	599	Bulk Carrier	Yes	Incorrectly coded in meters.
Los Angeles/ San Pedro/ Wilmington	70434	-	Auxiliary Vessel	No	Collision occurred in Marina del Rey
	70434	48	Motorboat	No	
	70692	119	Geophysical	Yes	
	70692	-	Motorboat	Yes	
	70651	-	-	No	Occurred in Utah
	70835	260	Barge	Yes	
	70835	-	Motorboat	Yes	
	70835	62	Tug	Yes	
	71207	564	Freighter	Yes	Collision occurred in Long Beach. Counted with Long Beach.
	71221	50	Fishing	No	Fishing vessels not counted.
	72006	-	Fishing	No	
	72032	-	Fishing	No	
	72033	62	Tug	Yes	
	72033	682	Bulk Carrier	Yes	Incorrectly coded in meters.
	72033	208	Barge	Yes	
	72034	155	Oil	Yes	
	72034	-	Naval Vessel	No	Naval vessels not counted.
	73068	660	Tanker	Yes	
	73073	45	Passenger	No	Location reported as unknown.
	73078	-	Motorboat	Yes	Collision occurred in Long Beach.
	73078	94	Tug	Yes	Counted with Long Beach.
	72559	-	Fishing	No	Fishing vessels not counted.
	71121	500-600	Public	Yes	
	71121	500-600	[illegible]	Yes	

PUGET SOUND (FY'77 VESSEL CASUALTY RECORDS)

Location	Case No.	Actual Length (feet)	Vessel Type	Collision Counted	Comment
Tacoma	70568	653	Foreign Freight	Yes	
	71728	107	Tug	Yes	
	71728	275	Barge	Yes	
	72351	80	Tug	Yes	
	72351	72	Tug	Yes	
	72351	465	Freight	Yes	
	73110	70	Tug	Yes	
	73110	80	Tug	Yes	
	73110	638	Freight	Yes	Incorrectly coded in meters.
Port Angeles	70957	35	Fishing	No	Fishing vessels not counted.
Port Townsend	71335	686	Bulk Carrier	No	Collision occurred at Cherry Point, Ferndale, Washington
	71335	110	Tug	No	
	71335	107	Tug	No	
	72159	35	Fishing	No	Fishing vessels not counted.
Everett	None				
Olympia	None				
Bellingham	70672	168	Barge	Yes	
	70672	84	Tug	Yes	
	70672	95	Tug	Yes	
	71725	105	Tug	Yes	
	71725	400	Barge	Yes	
	72335	110	Tug	No	Collision occurred at Ferndale, Washington
	72335	106	Tow	No	
	72335	400	Tank Barge	No	
Seattle	70251	600	Foreign Freight	Yes	
	70631	272	Barge	Yes	
	70631	317	Barge	Yes	
	70631	99	Tug	Yes	
	70737	200	Tank Barge	No	Intentional grounding. Location unknown.
	70960	80	Tug	Yes	
	70960	418	Ferry	Yes	
	71411	103	Tug	Yes	
	71411	572	Freight	Yes	Incorrectly coded in meters.
	71411	87	Tug	Yes	
	71411	93	Tug	Yes	
	71487	276	Barge	No	Location unknown.

PUGET SOUND (FY'77 VESSEL CASUALTY RECORDS) (continued)

Location	Case No.	Actual Length (feet)	Vessel Type	Collision Counted	Comment
Seattle (continued)	71546	96	Commercial	Yes	
	71550	400	Barge	Yes	
	71550	112	Tug	Yes	
	71550	415	Oceanography	Yes	
	72372	65	Tug	Yes	
	72372	200	Barge	Yes	
	72562	112	Tug	Yes	
	72562	110	Tug	Yes	
	72562	112	Tug	Yes	
	72562	302	Foreign Tanker	Yes	
	72710	103	Tug	Yes	
	72710	400	Barge	Yes	
	72710	127	Tug	No	
	72780	-	Foreign	No	4 miles off Neah Bay.
	72788	-	Fishing	No	
	73108	-	-	No	Collision occurred in Straits of Juan de Fuca
	73166	562	Freight	Yes	
	73166	117	Tug	Yes	
Anacortes	72565	-	Fishing	No	Fishing vessels not counted.

SAN FRANCISCO BAY (FY'77 VESSEL CASUALTY RECORDS)

Location	Case No.	Actual Length (feet)	Vessel Type	Collision Counted	Comment
Redwood City	None				
Oakland	71715	39	Yacht	No	Yacht abandoned in Ocean Beach
Richmond	70756	60	Yacht	No	Grounding occurred east of False River in Piper Slough.
	71666	300	Barge	Yes	
	71666	64	Tug	Yes	
	71666	121	Tug	Yes	
Stockton	70565	82	-	No	Grounding occurred at Cliff House Shoals in Sacramento River
San Francisco	70529	293	Dredge	No	Collision with Southampton Shoal Channel Light #4 in San Francisco Bay.
	70530	444	Barge	Yes	
	70530	123	Tug	Yes	
	70530	62	Tug	Yes	
	70530	72	Tug	Yes	
	70531	67	-	No	Grounding occurred near Fort Point in San Francisco Bay.
	70592	152	-	Yes	
	70827	120	Barge	No	Collision occurred at Madera Creek.
	70827	65	Tug	No	
	70916	700	Container	No	Collision occurred in San Francisco Bay.
	70916	-	Sailing	No	
	70995	623	Tanker	Yes	Collision occurred in Richmond. Counted with Richmond.
	70995	70	Tug	Yes	
	70995	63	Tug	Yes	
	71596	96	Tug	Yes	
	71596	113	Tug	Yes	
	71596	93	Tug	Yes	
	71596	820	Container	Yes	
	70993	82	Research	Yes	Coded as San Francisco Bay, however collisions occured in Richmond. Counted with Richmond.
	70[illegible]	579	Freighter	Yes	
	71020	118	Tug	Yes	
	71020	353	Cargo	Yes	
	72656	665	Auto Carrier	Yes	
	72656	293	Dredge	Yes.	
	73435	-	Tug	Yes	Coded as San Francisco Bay, Counted in San Francisco.
	73435	170	Barge	Yes	
	73436	600	Cargo 700	Yes	

HAWAII (FY'77 VESSEL CASUALTY RECORDS)

Location	Case No.	Actual Length (feet)	Vessel Type	Collision Counted	Comment
Kahului	72371	49	Yacht	Yes	
Honolulu	70202	32	-	Yes	
	70582	55	Fishing	No	Fishing vessels not counted.
	70605	127	Tug	Yes	
	70605	173	Foreign	Yes	
	70740	126	Foreign	Yes	
	71717	-	Motorboat	No	Collision occurred in Mamala Bay.
	71717	65	Passenger	No	
Nawiliwili	None				
Hilo	None				
Kawaihae	71443	135	Tow	No	
	71443	200	Barge	Yes	
	71443	175	Barge	Yes	
Kanakakai	70275	41	Motorboat	Yes	

ALASKA (FY'77 VESSEL CASUALTY RECORDS)

Location	Case No.	Actual Length (feet)	Vessel Type	Collision Counted	Comment
Wrangell	70123	65	-	No	Grounding occurred in Wrangell Narrows.
	70607	286	Barge	Yes	
	70607	172	Tug	Yes	
	71891	-	Barge	Yes	
	73557	-	Fishing	No	Fishing vessels not counted.
Sitka	70227	-	Fishing	No	Fishing vessels not counted.
	72598	-	Fishing	No	
	73540	-	Artificial Island	No	Collision occurred in Gulf of Alaska
	73540	-	Cargo	No	
Kodiak	70370	100	Cargo	No	Grounding at 57° 20' N 154° 30' W
	70719	80	Fishing	No	Fishing vessels not counted.
	70734	72	Fishing	No	
	70734	63	Fishing	No	
	71293	80	Fishing	No	
	71297	69	Fishing	No	
	71592	78	Fishing	No	
	71650	-	Fishing	No	
	72169	-	Fishing	No	
	71582	260	Barge	Yes	
Skagaway	70032	100 - 200	Foreign	Yes	
Valdez	None				
Seward	70214	82	Barge	No	Collision with submerged object away from port.
	70362	31	Fishing	No	Fishing vessels not counted.
Ketchikan	70300	49	Fishing	No	Fishing vessels not counted.
	70348	32	Fishing	No	
	70647	400	Barge	Yes	
	71222	-	Fishing	No	
	71902	-	Fishing	No	Fishing vessels not counted.
	71902	-	Fishing	No	
	71920	-	Fishing	No	
	72221	-	Fishing	No	
	72687	-	Tug	No	Collision away from port.
	72688	-	Fishing	No	
	72997	-	Fishing	No	Fishing vessels not counted.
	73000	-	Fishing	No	
	73000	-	-	No	Collision occurred in Kasaan Bay
	73549	-	Motorboat	Yes	
	73549	-	Fishing	No	Fishing vessels not counted.
	73554	-	Fishing	No	
Anchorage	70110	523	Cargo	Yes	
	71306	360	Cargo	No	Collision occurred in Captains Bay
	71321	53	LCM-3	No	Grounding in Nuka Passage
	71331	52	LCM-6	No	Grounding at 59° 26' N 150° 42' W
	71713	260	Barge	Yes	
	73539	-	Artificial Island	No	Collision occurred in Gulf of Alaska.
	[illegible]	-	Tug	No	

APPENDIX F - RELATIVE RANKING TEST

The relative ranking test applied in Sections V and VI was developed to give a quantitative measure of the Collision Prediction Model's ability to forecast the relative ranking of ports based on number of collisions. The ranking test is accomplished by listing the ports in descending (or ascending) order based upon historical results. If the Collision Prediction Model forecasted collisions in exactly the reverse order (port with most collisions last and port with least collisions first), that would be the worst possible case. A relative ranking indicator is achieved by taking the ratio of the CPM results with the worst possible case. A ranking indicator of 1.0 says that the CPM produced the worst possible results while a figure at 0.0 says the CPM matched the historical results exactly.

A Monte Carlo simulation was used to determine probabilities based on random ranking of the ports. The simulation, based on 1,000 cases, showed that the relative ranking indicator was normally distributed with $\mu = 0.5$ and $\sigma = 0.12$. Figure F-1 graphically illustrates this distribution. In addition, ranking the ports based on the number of transits was evaluated to determine whether or not the CPM produced more accurate results. The following conclusions can be drawn from Figure F-1:

1) The CPM forecasts are far from random. There is approximately one chance in 1,000 of equalling or bettering the CPM forecasts for 1977 based on random ranking of ports.

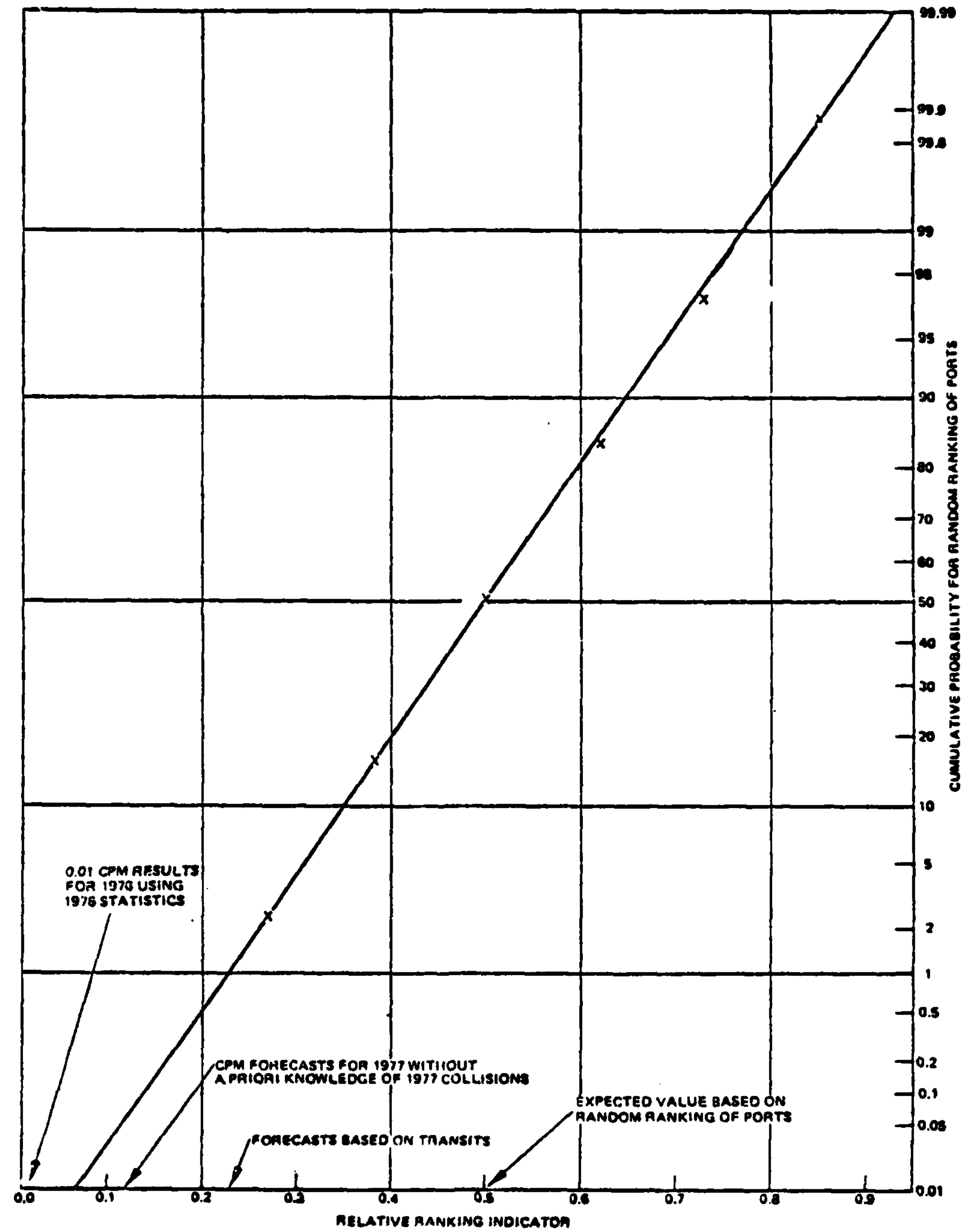

Figure F-1. Cumulative Probability of Achieving Relative Ranking Indicator

2) The CPM predictions closely match the exact results when collision statistics are included.

3) The CPM forecasts are better than ranking according to number of transits.

4) CPM forecasts can be used to rank ports.